

LIVING AND KNOWING: HOW NATURE MAKES KNOWLEDGE POSSIBLE

Michael Dix

ABSTRACT: Traditional human-centred epistemologies have failed to adequately address the question, ‘How are cognition and knowledge *possible*?’ Naturalistic epistemologies, however, and in particular, evolutionary, biosemiotic, and autopoietic approaches, have recognized that humans are not the only knowers, perceivers, cognizers and rememberers in nature, and thus ask instead, ‘How does *nature* make cognition and knowledge possible?’ thereby reconceiving epistemology as study of the cognition and experience of *living, embodied, interacting and inter-signifying natural beings*. Nonetheless, their insights into how nature makes knowledge (and other epistemological achievements) possible, while instructive, typically are incomplete – in most cases because key aspects of the peculiar physical/causal dynamics of cognitive processes and their causal/functional roles in the lives of organisms, are insufficiently considered. This paper seeks to redress this situation, to provide a clearer understanding of how nature makes knowledge (and other epistemological processes and achievements) possible.

The argument draws upon insights of the approaches mentioned, and upon studies of biological hierarchy, natural emergence, complex causal dynamics and hierarchically structured causal processes, to show that nature’s “inventions” of non-linear causation and cybernetic process-modulation led to the emergence of novel systems whose sensitivity to *ultra-low-energy* signals (for example, just a few molecules of a chemical compound) radically enhances their viability by producing a non-linear hierarchically ordered cascade of adaptive activity peculiarly associated with the signal type. This is *biosemiosis*. It is argued that the unique *causal* character of biosemiotic processes is not only their physical “signature”, but is essential to subsequently emergent cognitive processes and achievements and their functions, and indeed to the biological functions of the organic processes that make life possible. This is a further reason (if further reason were needed) for holding biosemiosis to be, ontologically, a natural kind. Indeed, an understanding of the distinctive causal/functional character of biosemiosis is the key to understanding how nature makes possible not only knowledge (and all other epistemological processes and achievements) but also, by those semiotic means, life itself.

KEYWORDS: Knowledge; biosemiosis; semiosis; signs; epistemology; cognition; biology; hierarchy; causation; complexity; non-linearity; evolution; umwelt; Uexküll; Sharov; Bickhard; Peirce; Kull; Hoffmeyer; Emmeche.

1. INTRODUCTION: HOW IS KNOWLEDGE POSSIBLE?

(a) *Outline of the argument*

In asking how knowledge is *possible*, the Western philosophical tradition considered only how knowledge is possible *for us*, ignoring the myriad other species of knowers, perceivers, cognizers and rememberers in nature. I will argue that to understand how *our* knowledge is possible requires that we understand how perception, memory, cognition and knowledge *emerged* in nature, prior to the evolutionary emergence of human beings. Theory from a number of fields is relevant here, particularly biosemiotic theory, whose central contribution is the insight that the evolutionary basis of all cognition is the emergence in nature of semiosis – the interpretation and making of signs – which occurred in the latter part of the history of the cosmos, but long before the evolution of human beings. My purpose in this paper is to argue that the key to understanding *how* biosemiotic processes function is to recognize that they distinctively embody a peculiarly effective form of non-linear causation within the hierarchically structured living systems in which they occur. This is the physical-systemic “signature” of biosemiosis. It is this distinctive mode of causation which underlies and *makes possible* all epistemological processes and achievements, and indeed life itself.

It is none of my intention to redefine or radically reconstitute epistemology (as for example occurs in Maturana and Varela’s theory of biological autopoiesis,¹ or in Plotkin’s universal Darwinism,² or Millikan’s reduction of linguistic meaning to naturally selected ‘evolved proper functions’ of linguistic terms).³ Rather, I seek to show how current epistemological concepts may be *illuminated* by an integrating framework that draws together insights of evolutionary, biosemiotic, complexity-theoretic, and *umwelt*-theoretic approaches. The integrating principle of this framework is an understanding of the mode of non-linear causation distinctive of biosemiosis, and of how it makes possible a world of emergent, co-evolving,

¹ H. Maturana & F. Varela, *Autopoiesis and Cognition: the Realization of the Living*, R.S. Cohen and M.W. Wartofsky (eds.), *Boston Studies in the Philosophy of Science*, vol. 42. Dordrecht: D. Reidel Publishing Co, 1980; and H. Maturana & F. Varela, *The tree of knowledge: The biological roots of human understanding*. Boston: Shambhala Publications, 1987.

² H. Plotkin, *Darwin Machines and the Nature of Knowledge*, Harmondsworth: Penguin, 1993.

³ R.G. Millikan, *Language, Thought and Other Biological Categories*, Cambridge, MA: MIT Press, 1984.

communicating, dynamically self-stabilizing, hierarchically structured living systems. It is the emergence in nature of this distinctive mode of causation that makes cognition possible.

(b) Inadequacies of the tradition

Let us first briefly consider how the Western philosophical tradition has approached the question, ‘How is knowledge possible?’

Plato, arguing that our knowledge is made possible by our prior acquaintance with a transcendent realm of Forms, told a fairytale of our souls’ former dwelling among those transcendent objects of adoration.⁴ Aristotle’s hylomorphism brought forms back to earth,⁵ while his psychology attributed to them the ability, when our senses chance upon them, to *in-form* our perceptions and thoughts – through a mysterious inward duplication of those same forms⁶ – not a fairytale, but no less a mystery. Like Aristotle, most of the subsequent representationalist tradition failed to see there was any problem with its assumption that perception, thought and knowledge could be a “mirror of nature” (as Rorty puts it in his critique of the tradition).⁷ Knowledge is possible, the representationalist tradition naively assumes, because thought and nature were made for each other, one to be image of the other.

Such complacency invited scepticism. It took the jolt of Hume’s scepticism to wake Kant ‘from his dogmatic slumbers’.⁸ In his *Critique of Pure Reason* Kant proposed that only if the mind itself were author of the forms of empirical possibility could thought and empirical world correspond.⁹ Nonetheless, Kant’s transcendental account of knowledge’s possibility still presupposes that knowers are beings such as us, consciously aware, with highly developed capacities for conceptualisation and understanding, reason, imagination, and intricately detailed perception, all integrated by unity of apperception and transcendental ego. As to how these are *made* possible, Kant argues only that since we are knowers our nature *must* be so.

Aside from Kant and the idealist tradition he influenced (particularly Schelling and German *Naturphilosophie*) the epistemological and scientific mainstreams were scarcely stirred in *their* philosophical slumbers by such questions as ‘How is knowledge possible?’ As positivism gained sway in the sciences and logical positivism subverted philosophical naturalism, radical philosophical questions were deemed ‘meaningless’,

⁴ Esp. *Republic*, Books 6&7.

⁵ Aristotle, *Metaphysics*.

⁶ Aristotle, *De Anima*.

⁷ R. Rorty, *Philosophy and the Mirror of Nature*. Princeton, NJ: Princeton University Press, 1979.

⁸ As Kant tells us in his *Prolegomena to any Future Metaphysics* of 1783.

⁹ I. Kant, *Critique of Pure Reason*

‘metaphysical’, or ‘undecidable’, and were treated as practically and theoretically worthless. But not by pragmatism, which kept alive and developed the program of philosophical naturalism.

For pragmatists, our question ‘How is knowledge possible?’ was answerable in terms of the greater usefulness and survival value of some practices, habits, and underlying neural formations. Capacity for knowledge was generally attributed to evolutionary developments in nature. Nonetheless, the *oddness* of knowledge – in a universe mostly comprised of *unknowing* things – was remarked only by a perceptive few.

One thing which, to a naturalistic epistemology, ought to seem most odd about knowledge, is its *consequentiality* – not merely that it should matter at all in a world of physical pushes and pulls, of four forces to which all attraction, repulsion, motion, combination and dissociation seem attributable – but that in its own modest domain knowledge should matter *so much!* Whence derives knowledge’s *power*, its characteristic *causal non-linearity*? (Non-linearity is disproportionality of “output” to “input”.) How can the comparatively minute neural energies associated with learning (and forgetting) be of such consequence – changing lives, changing history, even changing the planet?

To understand how knowledge is possible we must take seriously its oddness: only a study *of* its peculiarity – indeed, of the peculiarity of the entire gamut of epistemological categories – will suffice. Accordingly, my argument will draw upon approaches in philosophy and in the sciences which have acknowledged this peculiarity and made it their focus.

But to take seriously the imperatives of a naturalistic epistemology it must be recognized that humans are not the only knowers, perceivers, cognizers and rememberers in nature: there are myriad creatures whose survival depends on perceptual ability, memory, recognition of dangers and opportunities, and intelligent response to situations encountered. A naturalised epistemology must consider cognition *biologically*. Moreover, there are gradations of cognitive ability among species in nature, gradations which the biologist explains at least partly in evolutionary terms. To explain higher cognitive abilities in nature, it is necessary to understand their development from lower abilities. Thus a naturalistic approach to epistemology will inquire not only into the emergence of knowledge, but must ask, ‘What is it in nature that makes *cognition* possible?’ Accordingly, my inquiry will be as much a philosophical study *of nature* as it is an epistemological investigation, and my central question will be: ‘What is it in nature that makes cognition, and thereby knowledge, possible?’

2. MAKING A START: BIOLOGY, PHENOMENOLOGY AND SEMIOTICS

Fortunately, not all of epistemology was laid waste by positivism. *Development* of understanding, or growth of capacity for knowledge, could be studied empirically – as it was by Piaget and his school.¹⁰ A naturalised epistemology incorporates study of knowledge’s growth, and may investigate its evolutionary prehistory. We are biological beings immersed in and dependent on a world of multitudes of other biological beings, every one of which similarly is situated among and dependent on multitudes of others, and multitudes of kinds of others. *Knowing* fits us for life in this world. Is this so for humans alone? Biologists certainly have not thought so. *Knowledge* is a term that figures in the biological sciences, as do other terms from the epistemologist’s stock: *perception, learning, memory, interpretation, recognition, significance, experience*, and so forth. But here the question, ‘How are cognition and knowledge possible?’ becomes both more pressing and more tractable: more pressing because cognition and knowing are important to the survival of organisms that *can* cognise and know, and so need to be understood if we are to understand their survival; more tractable because the implicated processes of perception, learning, memory, cognition, interpretation, significance, experience, etc., can be studied in a range of beings, from “lower” to “higher”, and their development be thus better understood, and thereby the emergence of knowledge also.

Here, *phenomenological* study of the structure and character of experience is important: study of how it is to *be* a being that perceives, interprets, feels, remembers, thinks, knows and acts, in a world of other beings, including beings like oneself, a perceived-world of significance – a ‘life-world’ or *Umwelt*.¹¹ Accordingly, since experience, phenomenologically considered, is of things *as significant* – as *signs* of something – to understand how nature makes cognition and knowledge possible will require that our study consider the *semiotics* of cognition.¹² But the argument need not rest on this philosophical consideration alone, for biologists, in their practice and their theorizing, continually attribute to organisms powers of interpretation, cognizance of information, acts of signalling, recognition of signals and response to their meanings,

¹⁰ J. Piaget, *The Construction of Reality in the Child*. New York: Basic Books, 1954; and *The Principles of Genetic Epistemology*. New York: Basic Books, 1972.

¹¹ E. Husserl, *Ideas Pertaining to a Pure Phenomenology and to a Phenomenological Philosophy—Second Book: Studies in the Phenomenology of Constitution*, trans. R. Rojcewicz and A. Schuwer. Dordrecht: Kluwer, 1989; A. Schutz, *The Phenomenology of the Social World*. Evanston, IL: Northwestern University Press, 1967; J. von Uexküll, ‘An introduction to Umwelt’, *Semiotica*, no. 134, 2001, pp. 107-110.

¹² J. von Uexküll, ‘The theory of meaning’, *Semiotica*, no. 42, 1982, pp. 25-82.

and so forth.¹³ A principled account of the origins of semiotics *in nature* will make good on this commitment of biologists.

But *how*, it might be asked, can interpretation, significance, experience, and the like, be studied in non-humans – how can we understand the inner lives of beings very different from ourselves? Here I think it is important to “nip in the bud” a possible misunderstanding. We will *not* need to discover, for example, *what it is like phenomenally to experience as a bat experiences* – in the sense of Thomas Nagel’s well-known philosophical discussion ‘What is it like to be a bat?’¹⁴ Rather, it will be sufficient to conjecturally posit merely *structural* features or *functional* relationships in bat perception and cognition (as Nagel recognizes we may). To take another example, it is known that the feature detectors of a frog’s vision are responsive to dots moving across the frog’s visual field, but not to stationary dots.¹⁵ Thus it is hypothesised that moving dots (possibly insects) will be salient in a structural/functional understanding of frog perception, while stationary dots (even if they are insects) will be unnoticed and have no role in a conjectured phenomenology of frog vision – that is, in the perceived-world or *umwelt* of the frog. Thus, although non-human animal experience may be very different from human experience, this will not make it impossible to study.

Indeed, *human* experience very different from our own is already studied phenomenologically. Neurologists, for example, may endeavour to construct clinical phenomenological understandings of their patients’ neurological pathologies. Some fascinating cases are described by Oliver Sacks.¹⁶ Of course, the neurologist may converse with the patient, whereas the biologist cannot converse with the organism, but a biologist’s reconstruction of the simpler phenomenology of an organism’s

¹³ K. Kull, C. Emmeche, & J. Hoffmeyer, ‘Why Biosemiotics? An Introduction to Our View on the Biology of Life Itself’, in C. Emmeche, and K. Kull (eds), *Towards a Semiotic Biology: Life is the Action of Signs*, London: Imperial College Press, 2011, pp. 1-21; K. Kull, T. Deacon, C. Emmeche, J. Hoffmeyer, & F. Stjernfelt, ‘Theses on Biosemiotics: Prolegomena to a Theoretical Biology’, in C. Emmeche and K. Kull (eds), *Towards a Semiotic Biology: Life is the Action of Signs*, London: Imperial College Press, 2011, pp. 25-41; J. Hoffmeyer, ‘Biology is Immature Biosemiotics’, in C. Emmeche and K. Kull (eds), *Towards A Semiotic Biology*, London: Imperial College Press, 2011, pp. 43-65; and Y. Neuman, ‘Why Do We Need Signs in Biology?’ In C. Emmeche, and K. Kull (eds), *Towards a Semiotic Biology: Life is the Action of Signs*. London: Imperial College Press, 2011, pp. 195-209.

¹⁴ T. Nagel, ‘What is it like to be a bat?’ *Philosophical Review*, vol. 83, no. 4, 1974, pp. 435-50.

¹⁵ J.Y. Lettvin, H.R. Maturana, W.S. McCulloch, & W.H. Pitts, ‘What the frog’s eye tells the frog’s brain’, in W.C. Corning, & M. Balaban (eds), *The Mind: Biological Approaches to its Functions*. New York : Interscience Publishers, 1968, pp. 233-58.

¹⁶ O. Sacks, *Awakenings*. London: Duckworth; New York: Doubleday, 1973; *The Man Who Mistook His Wife for a Hat*. London: Duckworth; New York: Summit Books, 1985; *An Anthropologist on Mars*. New York: Alfred A. Knopf; London: Picador, 1995; *The Island of the Colorblind*. New York: Alfred A. Knopf; London: Picador, 1996.

*umwelt*¹⁷ may present no greater difficulty than does the task of the neurologist in understanding the patient's (more complex) experiential pathology.

3. JACOB VON UEXKÜLL: THE *UMWELT* OF AN ORGANISM IS A WORLD OF SIGNS

To understand an organism and its behaviour we need to understand its "world": that is, what things and relationships are salient for it, and why. Insects see in the ultraviolet; we do not. Sharks and platypuses can sense electric fields; some cetaceans have a sense using sonar capable of perceiving even internal organs of other creatures. The perceived-world or *umwelt* of an organism will be comprised only of what can be salient for it, given its sensory abilities and sensory/cognitive limitations. This insight of the biologist Jacob von Uexküll (first published in 1909) has led to an appreciation of an organism's *umwelt* as comprising whatever has meaning or significance for it: that is, as a world of *signs* which mediate the organism's interaction with the world at large.¹⁸

In a later section I will show how this conception of salience is an advance on crude stimulus-models of what is salient for the organism's behaviour. Here though I particularly want to note how *umwelt* theory has been extended by later theorists¹⁹ – particularly in ways facilitating an understanding of the theorist and theory as located *within* the "subject-matter" of inquiry. This is a matter of methodological, epistemological, and ontological importance. Fraser sees it as follows:

The extension of Uexküll's *Umwelt* principle to worlds we know only through experiments and/or instruments and/or mathematical models is the extended or generalized *Umwelt* principle. Of course, the *Umwelten* of molecules, galaxies, birds and bees, baboons and babies, as revealed to us, become part and parcel of our own, *noetic Umwelt* or reality. The relation between the *Umwelten* is a hierarchically nested one. Our noetic reality includes those of photons and ticks; the *Umwelten* of photons and ticks do not include the *Umwelten* of horses or paleolithic artists.²⁰

¹⁷ See J. von Uexküll, *Theoretical Biology*. New York: Harcourt, Brace & Co, 1926; J. von Uexküll, 'A Stroll Through the Worlds of Animals and Men: A Picture Book of Invisible Worlds', in *Instinctive Behavior: The Development of a Modern Concept*, ed. and trans. Claire H. Schiller. New York: International Universities Press, Inc., 1957, pp. 5-80; J. von Uexküll, *A Foray into the Worlds of Animals and Humans, with a Theory of Meaning*, trans. Joseph D. O'Neil, Minneapolis: University of Minnesota Press, 2010.

¹⁸ *Ibid.* Also J. von Uexküll, 'An introduction to Umwelt', *Semiotica*, no. 134, 2001, pp. 107-110.

¹⁹ E.g. J.T. Fraser, 'The Extended Umwelt Principle: Uexküll and the Nature of Time', *Semiotica*, no. 134, 2001, pp. 263-273. For a history of the concept, see U. Sutrop, 'Umwelt, Word and Concept: Two Hundred Years of Semantic Change', *Semiotica*, no. 134, 2001, pp. 447-462.

²⁰ Fraser, *op. cit.*, p. 265.

Those specialised, theoretical *umwelten* are never “views from nowhere” as traditional and positivist conceptions of scientific and epistemological objectivity supposed theory ought to be. Rather, they are embedded worlds of significance under development *for* and *by* us. (And while it may seem odd to apply – but now only metaphorically – the concept of *umwelten* even in the case of molecules and photons – which of course are not really observers, and do not really have life-worlds or perceived-worlds – it will seem much less odd when we recall the importance of thought-experiments of twentieth-century physics which took precisely this approach, albeit without using the term *umwelt*.) Theoretical *umwelten* are made possible by the *umwelten* in which they are embedded and which they elaborate and explain. Reality, then, is always reality-*for-us* – our ‘noetic reality’ as Fraser calls it – but the principled inclusiveness and transformative development of our *umwelten* make them far from merely subjective realms of limitation, for we and they are transformed by our discovery and investigation of them.

But how are *umwelten* – of whatever sort, and whether ours, or those of other species – *made possible*? How did nature conjure the first *umwelten* out of mere matter and energy, and provide for their subsequent development as species evolved? The key to answering these questions is the distinctive causal character of biosemiosis.

4. BIOSEMIOSIS: THE SEMIOTIC, HIERARCHICAL NATURE OF LIFE AND ITS EVOLUTION

An organism is a *partial* (or “biased”) interpreter of itself, its condition, and its environment. This partiality is reflected in its *umwelt*, since the organism’s biological needs make only some features of its environment salient or significant for it. To adequately theorize the organism’s relationship to “the world at large” (understood in terms of *our* ‘extended *umwelt*’) we need to recognize that this relationship is essentially mediated by the organism’s partiality as an interpreter of the signs afforded by its *umwelt*, that is, by the *significance* of what is salient for it. This is the rationale motivating research in the field of biosemiotics.

Biosemiotics is an emerging approach to biology which sees meaning and interpretation as crucial for living systems, and semiotic processes as both essential to life, and the key to biological evolution. Its scientific theorists – natural philosophers in the fullest sense – aim to develop, *in the service of biology*, a naturalistic, but non-anthropocentric, epistemology and ontology of signifying and interpretation. Using this naturalised semiotics they reinterpret and extend established findings from the sciences of the modern evolutionary synthesis, and even some of the physical sciences.

The broader theoretical motivation for biosemiotics is commitment to a natural philosophy of hierarchical emergence.

An especially clear sketch and application of the biosemiotic approach is Alexei Sharov's 'The Origin and Evolution of Signs'.²¹ Here Sharov argues that the origin and evolution of signs are one and the same with the origin and evolution of life: 'that life is communication, and that the contents of communication is how to live, i.e. how to communicate', life's evolution being 'characterized by increasing complexity of communication'. Since signs require interpreters, and *vice versa*, they must have originated and evolved together. Sharov argues that they originated with the emergence of autocatalytic systems. (A catalyst is a substance that accelerates a chemical reaction without undergoing any permanent change itself; in autocatalysis the catalyst is one of the products of the reaction, this constituting a feedback loop in the chemical process.) An autocatalytic system, in Sharov's sense, is contained within some sort of perimeter, but is thermodynamically open (receiving energy and chemical "feedstock" from outside), and is catalytically self-sufficient. In this way, an autocatalytic system is self-maintaining even though it remains in dynamic disequilibrium. Sharov hypothesises that life originated with systems of polymer autocatalysis.

Such systems, he thinks, may be deemed semiotic firstly because they would be responsive: certain signals (primitive signs) would prompt certain actions or responses (primitive interpretations) in the system (for example, selective incorporation of monomers – polymers are comprised of chained monomers). Secondly, inasmuch as such systems are dynamically self-responsive, they are self-interpreting, thereby exhibiting what the physicist Pattee terms 'semantic closure'.²² And thirdly, not only are autocatalytic systems self-maintaining, they may be self-reproducing: budding-off polymeric replicas of themselves which thereby already incorporate the information needed to be likewise dynamically self-maintaining and self-reproducing.²³ This last is an instance of what Hoffmeyer terms vertical semiosis.²⁴ Of course, unlike the

²¹ A. Sharov, 'The Origin and Evolution of Signs', *Semiotica*, no. 127, 1999, pp. 521-535.

²² H.H. Pattee, 'Evolving Self-Reference: Matter, Symbols, and Semantic Closure', *Communication and Cognition*, vol. 12, 1995, pp. 9-27.

²³ For a conjectural discussion, see e.g. S.A. Kauffman, *The Origins of Order: Self-Organisation and Selection in Evolution*, New York: Oxford University Press, 1993.

²⁴ J. Hoffmeyer, *Signs of Meaning in the Universe*, Bloomington: Indiana University Press, 1996; and *Biosemiotics. An Examination into the Signs of Life and the Life of Signs*, Scranton PA: University of Scranton Press, 2008.

paradigmatic form of vertical semiosis accomplished by means of coded DNA,²⁵ this primitive form involves no code.

Sharov holds that those reasons for describing such autocatalytic systems as semiotic, are equally reasons for deeming them to be alive, and that their emergence in nature is thus the emergence of life. Less controversial is his view that vertical semiosis is at the root of life's evolution,²⁶ although his assumption that all subsequent evolution likewise occurs through autocatalysis may be controversial. My own view is that whether one describes systems of polymer autocatalysis as alive, or (alternatively) as proto-life or pre-life, what is most important is that they are capable of selectively *discriminating* aspects of their environment and of selectively responding. This is semiosis. I would prefer to describe these systems as proto-semiotic *precursors* of living systems, rather than as already *biosemiotic*, because they lack the hierarchical-functional complexity of living systems, and do not require the delicate forms of hierarchical feedback and modulation that only biological semiosis affords (see the section, 'Pushes, prods, and prompts', below).

The *meaning* of an environmental sign for a primitive semiotic system will be an action or response, not a representation somehow "held" within the system. No such representation is possible or necessary in these systems. With regard to viability, reproduction, and evolution, some of the actions available to systems as possible interpretations of a given sign may make a greater contribution than others. Which interpretation a system makes may thus have significance for its survival and reproduction, and ultimately for the evolution of a lineage.²⁷

Next to emerge in the evolution of semiotic strategies of life is cooperation. Sharov argues that this occurs through the incorporation of numbers of autocatalytic systems into metasegments, in which each member affords products (signs) for others and is the recipient (interpreter) of others' products (signs).²⁸ Within these internally differentiated metasegments, cooperative strategies symbiotically co-evolved in which communication between metasegment components integrated development of 'hypercycles' of 'metasegment transitions'. (Metasegment transitions can occur at various hierarchical levels of scale. Hypercycles involve embedded and/or serial causal complexity.) The advantages of such strategies may include hierarchical buffering of components, availability of compensatory systems in cases of component failure, more effective information gathering, increased specialisation, and increased hierarchical

²⁵ M. Barbieri, *The Organic Codes. An Introduction to Semantic Biology*, Cambridge: Cambridge University Press, 2003; and 'Life is Semiosis', *Cosmos and History*, vol. 4, no.1-2, 2008, pp. 29-52.

²⁶ See also Hoffmeyer, 1996 and 2008; and Barbieri, *ibid*.

²⁷ Sharov, 1999.

²⁸ *Ibid*.

control. What Sharov stresses here is that cooperation is essentially communication, and involves a new level of semiosis: ‘horizontal semiosis’.²⁹ From such semiotic strategies evolved the cell, the organism, communities of organisms, and so forth.

Here we may pause in this conjectural evolutionary history of biosemiosis to note an important disagreement between two schools of biosemiotic thought. The evolution of sub-system cooperation within biological metasystems would appear to be a necessary condition for the emergence of semiotic *codes* such as the genetic code. However, contrary to the approach of Sharov, Kull, Sebock, Hoffmeyer, Emmeche and indeed the majority of biosemiotic theorists, an alternative theoretical approach holds that biosemiosis essentially occurs *through* the operation of codes, and thus must have emerged contemporaneously with the emergence of natural codes.³⁰ I think this view is mistaken for two reasons. The first is its seeming refusal to acknowledge that a biological system’s recognition of *non-coded* signals *as* signals (that is, as *signs*) is genuinely semiotic (since it is an interpretation of the signal’s *meaning* for the system). This refusal seems arbitrary. The second is its seeming failure to recognize what is *physically* unique to and distinctive of semiosis – its causal signature – which is a quite distinctive form of non-linear causation. I elaborate on this in section 5 below.

Returning now to Sharov’s conjectural evolutionary history of semiosis, we note that all semiosis to this stage involves *signals* – primitive signs – signs ‘immediately interpreted as actions’.³¹ These are in effect evaluated (by a living system, metasystem, co-operative community, or lineage) according to the reproductive value of their respective interpretations – this is their ‘significance’ for the system, ‘their usefulness’, as Sharov calls it. Values, that is, values *for* a system, emerge with *function* – that is, in relation to the functional importance of a particular sign-type for the survival or reproduction of the system.

The foregoing stages of semiotic evolution will have resulted in the emergence of single-celled organisms, and, through evolution of cellular cooperation and hierarchical functional self-organization, nucleated single-celled organisms, multicellular protists (slime moulds), plants, and animals. However, the next phase of semiotic evolution introduces a new form of interpretation and evaluation: the conceptual interpretation of proper signs, which makes possible evaluation as to truth or falsity. Sharov explicates the semiosis of proper signs in terms of Peirce’s triad of

²⁹ See also Hoffmeyer, 1996 and 2008.

³⁰ See for example Barbieri, 2003 and 2008. For critical discussion see K. Kull, C. Emmeche, & J. Hoffmeyer, ‘Why Biosemiotics? An Introduction to Our View on the Biology of Life Itself’, in C. Emmeche and K. Kull (eds), *Towards a Semiotic Biology: Life is the Action of Signs*, London: Imperial College Press, 2011, pp. 1-21.

³¹ Sharov, 1999.

object, sign, and interpretant, linking this with the account of earlier phases of semiosis via a simplified version of Peirce's philosophical pragmatism.³² Reproductive value is deemed a prime form of pragmatic value, while truth is that which the interpreter is prepared to trust as the best conceptual means for modelling goal-oriented action (this being itself indirectly related to self-maintenent and reproductive value). The main differences between proper signs and signals are that the former permit semiotic evaluation via conceptual modelling, rather than requiring that interpretation be directly open to testing in action, and secondly that a proper sign may have multifarious uses and hence interpretations. (See section 7 below for discussion of epistemological implications of these distinctions.)

5. PUSHES, PRODS AND PROMPTS: THE ESSENTIAL CAUSAL NON-LINEARITY OF BIOSEMIOTIC MODULATION OF MULTIPLE LEVELS OF ORGANIC FUNCTIONING

(a) *Modelling causal processes: three phases of modern science*

There have been three broad phases of modern physical science. As Warren Weaver put it, 'physical science before 1900 was largely concerned with two-variable problems of simplicity',³³ then, in the nineteenth and twentieth centuries, various sciences developed ways of statistically modelling and understanding what Weaver terms 'disorganized complexity': systems whose dynamics involved 'perhaps billions' of variables.³⁴ For a considerable time, these stochastic methods were the only means of representing complexity. (In some fields today complexity is treated as if they were still the only means.) However, in its most recent phase (beginning around the time Weaver wrote) science has turned its attention to 'problems ... of organized complexity'; these 'involve dealing simultaneously with a sizable number of factors which are interrelated into an organic whole'.³⁵

³² *Ibid.*; also A. Sharov, 'Umwelt theory and pragmatism', *Semiotica*, no. 134, 2001, pp. 211-228. Sharov draws selectively on Peirce; cf. C.S. Peirce, *Collected Papers of Charles Sanders Peirce*, (8 vols), C. Hartshorne, P. Weiss and A.W. Burks (eds), Cambridge, Mass.: Belknap Press, 1931-1958, or (more conveniently) C.S. Peirce, *The Essential Peirce, Selected Philosophical Writings, Volume 1 (1867-1893)*. Nathan Houser and Christian J. W. Kloesel (eds), Bloomington and Indianapolis, IN: Indiana University Press, 1992, and *The Essential Peirce, Selected Philosophical Writings, Volume 2 (1893-1913)*, Peirce Edition Project (eds), Bloomington and Indianapolis, IN: Indiana University Press, 1998.

³³ W. Weaver, 'Science and Complexity', *American Scientist*, vol. 36, 1948, pp. 536-544.

³⁴ *Ibid.*

³⁵ *Ibid.* For general introductions to complexity theory, see R. Lewin, *Complexity: Life at the Edge of Chaos*, 2nd edition, Chicago and London: The University of Chicago Press, 1999, and A. Gare, 'Systems Theory and Complexity: Introduction', *Democracy and Nature*, vol. 6, no. 3, 2000, pp. 327-339.

The first phase of modern science (its Newtonian, mechanistic-reductionist phase) assumed that causation was simple, linear, deterministic, mechanical and unidirectional – a conception that survives today in popular belief. While this causal model was inappropriate for the second (probabilistic) phase of modern science, it was quite some time before indeterminist probabilistic analyses of causation were developed. However, both the former and the latter afford little understanding of the types of complex processes of interest in the third and most recent phase of modern science. Indeed, it is only comparatively recently that causal theory has begun to respond to this third phase by incorporating scientific insights regarding the *generic* characteristics of various types of complex dynamics.³⁶ For it has been one of the most striking discoveries of complexity science that similar complex dynamics and patterns of self-organizing emergent order may be found in very different processes, at widely different levels of spatiotemporal scale, and involving quite different sub-processes, entities, materials and forms of energy. A new scientific vocabulary has appeared, including such terms as ‘the edge of chaos’ (designating a dynamic regime of organised complexity identified by its generic characteristics)³⁷ and ‘excitable media’ (designating physical systems comprised of multiple, similar, interacting units – such as living cells – among which signal propagation and feedback can induce spontaneous emergence of generic forms of rhythmically propagating macroscopic self-organisation).³⁸ It is upon this emerging array of *generic* dynamic models that I will draw to show why and how biosemiosis is crucial for living beings and living processes.

(b) *Hierarchy theory*

Hierarchy theory provides an understanding of contexts of emergence, and of how emergents themselves can be self-organizing contexts for emergence. It allows also a clearer understanding of the coherence, robustness and resilience of emergents. And

³⁶ E.g. Kauffman, *op. cit.*; J. Cohen & I. Stewart, *The Collapse of Chaos: Discovering Simplicity in a Complex World*, London & New York: Penguin, 1995; B. Goodwin, *How the Leopard Changed Its Spots: The Evolution of Complexity*, London: Phoenix, 1995; S.N. Salthe, *Evolving Hierarchical Systems: Their Structure and Representation*, New York: Columbia University Press, 1985, and S. N. Salthe, *Development and Evolution: Complexity and Change in Biology*, Cambridge, MA: MIT Press, 1993; C. Emmeche, S. Koppe & F. Stjernfelt, ‘Levels, Emergence, and Three Versions of Downward Causation’, in P.B. Andersen, C. Emmeche, N.O. Finnemann, & P.V. Christiansen (eds), *Downward Causation: Minds, Bodies and Matter*, Aarhus: Aarhus University Press, 2000, pp. 13-34; R. Solé & B. Goodwin, *Signs of Life: How Complexity Pervades Biology*, New York: Basic Books, 2000; T.W. Deacon, *Incomplete Nature: How Mind Emerged from Matter*, New York: W.W. Norton & Company, 2012.

³⁷ See e.g. Solé & Goodwin, *op. cit.*

³⁸ See e.g. *ibid.*, pp. 21-25.

it is indispensable for an understanding of processes of biosemiosis and their importance.

In natural ‘scalar’ hierarchies – that is, “nested” hierarchies, in which higher levels of scale subsume lower levels; for example, an organism subsumes/contains its organs, which subsume/contain their cells, which subsume/contain their organelles, which subsume/contain complex molecules, etc.³⁹ – different levels typically operate at different rates of activity. The dynamics of higher-level processes – their rates of contextual and lower-level sampling, and intra-level activity – typically are slower than those of the lower-level processes which subserve them.⁴⁰ This enables hierarchically constituted living systems to be robust in the face of perturbation (whether from life’s “slings and arrows”, or life’s opportunities). As mentioned earlier, living systems are *not* in equilibrium; they function far-from-equilibrium, at the ‘edge of chaos’, which is the realm of organized complexity and emergence. In systems far from equilibrium, small variations may be vastly amplified – as in the so-called “butterfly effect”. This is particularly so in a hierarchical system when propagation of a small perturbation of one sub-system entrains the activity of further sub-systems resulting in a non-linear cascade which ultimately may place at risk – or alternatively preserve – the viability of the whole hierarchical system. For example, the minute energies of a few barely audible words, their faint vibrations entering the ear and transduced by the inner ear into minute neural signals, these entraining auditory-cognitive sub-systems of the brain and further systems of memory, affect, cognition and motivation, in a neural cascade which now entrains efferent sub-systems and the vastly greater energies of bodily activity, might have life-changing (or, for some, even life-ending) consequences.

However, the hierarchical constitution of living systems also operates to *reduce* their vulnerability to life’s “slings and arrows” and to inadvertencies of the “butterfly effect”. For systems of hierarchical *damping* may largely confine the consequences of perturbation to a single systemic level. This occurs in two ways. First, the larger scale and slower rates of functioning of higher levels in a scalar hierarchy mean that disturbance in the level below will be “sampled” relatively infrequently by the higher level, and thus may be partly or even wholly “invisible” to it – in other words, sampling infrequency is a form of natural non-linear damping of transmission of disturbance from lower to higher. (The higher level of course may still be vulnerable to disturbances from the lower of types it is unable to sample.) Whereas, secondly, at

³⁹ See Salthe, 1985 and 1993, for the distinction between ‘scalar’ hierarchies and ‘specification’ hierarchies.

⁴⁰ See *e.g.* R.V. O’Neill, D.L. DeAngelis, J.B. Waide & T.H.F. Allen, *A Hierarchical Concept of Ecosystems*, Monographs in Population Biology, no. 23, Princeton, NJ: Princeton University Press, 1986.

the level below the disturbance, many activity cycles will have been completed while the disturbance develops more slowly above, the faster rate of functioning of the lower level allowing it sufficient time for adaptive adjustments and/or equilibrative dispersion of shock, and thus to resiliently absorb the transmitted disturbance without harm.⁴¹

Recognition that in a resilient (that is, a *viable*) scalar hierarchy, disturbance in one level typically will be damped at the levels immediately above and below, motivates Salthe's methodological triad of a 'focal' level, a 'constraining' level immediately above, and a subserving level immediately below the focal level.⁴² To understand hierarchical functioning at a given level of living process, it normally will not be necessary to consider *all* functional levels of the system, because the perturbatory influence on the focal level of levels above or below that triad normally will be within the capabilities of the system to accommodate.

(c) *Causal emergence and natural hierarchies*

There are deep theoretical issues and debates concerning causation in natural hierarchies.⁴³ I will broach these only insofar as is absolutely necessary.

My commitment to philosophical naturalism leads me to accept an ontology in which

Everything is organizations of quantum processes... [and] causality is constraints on that quantum field activity, such as those that yield momentum or energy conservation.⁴⁴

However, this is not a reductive ontology, for organization – patterning of causal constraint – is emergent and ontologically real. In sketching the history of cosmic emergence, Bickhard and Campbell draw on contemporary theory in evolutionary cosmology:

The universe at its origin was a superhot flux of quantum fields; everything since then is the result of condensation, symmetry breaking, and organization out of that original flux, sometimes with clear hierarchical levels of organization. Quark excitations stabilize in combinations with other such excitations into nucleons,

⁴¹ See O'Neill *et al.*, *op. cit.*; Salthe, 1985 and 1993; and Deacon, *op. cit.*

⁴² Salthe, *ibid.*

⁴³ For discussion from a variety of perspectives, see P.B. Andersen, C. Emmeche, N.O. Finnemann, & P.V. Christiansen (eds), *Downward Causation: Minds, Bodies and Matter*, Aarhus: Aarhus University Press, 2000; see T.W. Deacon, *op. cit.*, for critique of some of these perspectives.

⁴⁴ M.H. Bickhard & D.T. Campbell, 'Emergence', in P.B. Andersen, C. Emmeche, N.O. Finnemann, & P.V. Christiansen (eds), *Downward Causation: Minds, Bodies and Matter*, Aarhus: Aarhus University Press, 2000, p. 327.

which combine with electrons to form atoms, which combine chemically to form molecules, which combine gravitationally to form planets or in derivative chemical ways to form rocks, water, cats, humans, and, presumably, minds.... Note that successively higher levels often require successively lower temperatures to emerge.⁴⁵

I will pause here to briefly explain and illustrate the concept of physical emergence, drawing on the example of chemical emergence. Early in the history of the universe there were no chemicals and no chemical reactions: because the pre-chemical universe was too energetic to permit the formation of atoms with their distinctive electron-shells – these being essential for chemical activity. That is, chemical processes *emerged* only when energy levels in relevant portions of the universe had sufficiently cooled. Chemical causal process is therefore different from, say, the processes of nuclear fusion and fission which produce the chemical elements and disperse them into cooler regions of the universe, and which are thus prerequisite for the emergence of chemical processes. Hence we may say that chemical causation is an example of *emergent causation* – or as Bickhard and Campbell term it, ‘emergent causality’, as when they stress that ‘Emergence which is non-trivial is emergent causality’.⁴⁶

Bickhard and Campbell argue that emergent causality will ‘necessarily involve downward causality’.⁴⁷ What they mean here is that hierarchically nested systems are prerequisites for causal emergence: downward causation being constraint on the activity of sub-systems by the activity of the superordinate system of which they are sub-systems. Here the distinction between linear and non-linear processes becomes crucial. Linear causation can be accounted for without postulating a new ontological level; thus *non-linearity* is a criterion for hierarchical emergence which is ‘non-trivial’,⁴⁸ and hence for emergent causation. At each level of emergence, new modes of non-linear causal process appear.

To go beyond this brief sketch of emergent causation would require a theoretical paper in itself, so I will proceed directly to a consideration now of how the natural emergence of biosemiosis constitutes an emergently novel mode of causation in its character as physical process.

⁴⁵ *Ibid.*, p. 325.

⁴⁶ *Ibid.*, p. 334.

⁴⁷ *Ibid.*, p. 333.

⁴⁸ *Ibid.*, p. 334.

(d) *Comparing pushes, prods, and prompts: how to recognize biosemiotic causation*

I have several times stressed that biosemiosis requires only tiny exchanges of energy between sign and interpreting system. Now I want to explain why this is so by contrasting the energy exchanges involved respectively in what I shall term pushes (together with pulls and pressures), prods and prompts, to show why it is that biosemiosis is primarily and paradigmatically through the type of physical causal process characteristic of prompts, rather than the grosser types characteristic of pushes or prods.

Pushes: Consider the ways in which the functioning of a system may be physically modulated. Simple mechanical systems function linearly by means of pushes, pulls and pressures. A bicycle is such a system. Another is a simple feedback system such as a mechanically governed steam engine; this too is modulated by pushes, pulls and pressures. The energies required for modulation of those simple systems are considerable – much greater than those modulating one’s heart-rate for example. This is so too with regard to human action involving pushes and pulls. Suppose, for example, someone intentionally gives me a shove – perhaps wishing me to step forward as a volunteer. Only part of their purpose is semiotic; the shove accomplishes the remainder of its purpose non-semiotically. If, physically, biosemiosis were typically like this, it would be extraordinarily wasteful of energy. And it might also be counter-productive, because the magnitude of energy transfer might produce deleterious consequences. (A shove, for example, instead of inducing me to step forward as a volunteer, might cause me to overbalance and fall on my face.) Given the many thousands of biological modulation and control systems involved in our highly complex bodily functioning – at the levels of organism, organs, cells, and sub-cellular processes – we will need much more energy-efficient modes of sampling, feedback and control than could be provided by mere infliction of pushes and pulls.

Prods: The situation of living things is complicated further by hierarchical biology. A *prod* (a less energetic, more focused type of push) may wake me from sleep or reverie, but the transmitted energies of a prod to the eye, for example, might be so great as to blind me. In other words, it is important that non-essential causal aspects of the sign-vehicle not physically overwhelm or destabilize the interpreting system or its sub-systems (preventing or impeding interpretive-responsive activity). Nonetheless, a prod may convey *meaning* – a prod may be interpreted as a *sign* – an instance of biosemiosis. However, it is still a very inefficient sign (even if sometimes effective). If every *cell* needed so comparatively energetic a signal before it allowed ingress of nutriment or egress of waste, our bodies could not function! The excessive physical energy of prod, then, is not typical of biosemiotic causation. Rather, it is only because

living systems are already served by vastly more energy-efficient forms of communication that are much less likely to cause damage or destabilization, that prods can sometimes be recruited to semiotic effect.

Prompts: Paradigmatically, semiosis requires initial transfer or conversion of very little energy – physically, this is characteristic of a prompt rather than a prod. Ideally, in biosemiosis the physical sign-vehicle (for example, reflected light reaching the retina) will be of sufficiently low energy for no damage to be caused to the sensory system. (In contrast, an image transmitted by an array of lasers might blind me.) A second reason why energy transfers involved in semiosis need to be small is so that the interpreting system not be destabilized by the energy demands of interpretation before the process of interpretation is able to yield an *interpretant* – Peirce’s term for the causally constituted physical action-potential which (we might say) is the pragmatic meaning of the sign for the interpreting system.⁴⁹ Initial transduction of a low-energy signal (for example, at the retina) will itself be of low-energy, but will prompt *entrainment* of further discriminatory physical processes (such as activation of the brain’s visual feature-detectors, memory of other signs, etc.) and possibly motor activity (such as exploratory behaviour). This process of entrainment is non-linear, and is a second definitive physical characteristic of biosemiosis.

But there is also a third distinctive causal feature of biosemiosis: the nuanced cascade of non-linear consequences prompted by the sign is *hierarchical*. Earlier I resisted Sharov’s description of primitive autocatalytic polymeric systems as *biosemiotic living* systems. I would prefer to call them semiotic precursors of life (assuming that they *are* the precursors of living things). This is firstly because there may have been only one signal, or very few, that the system was capable of reacting to – such that in each case the signal is effectively no more than a *switch* for “turning on” a particular activity. Secondly, although the autocatalytic system’s response to the sign is non-linear, it is possible that the system is too simply structured to have involved a *hierarchical* cascade of internal activity (as biosemiosis paradigmatically requires). In such a case, there is primitive molecular semiosis, but no life. However, I suppose that if a primitive autocatalytic self-maintaining polymeric system were also self-reproducing (by budding-off copies of itself) there might be some reason for describing it as alive, but even in this case I would prefer to reserve this description for the time when the now numerous autocatalytic systems begin responding to signs produced by each other – that is, when there emerges the new hierarchical level of a *community* of semiotic systems.

⁴⁹ I simplify here; Peirce, 1931-1958, characterizes interpretants in many ways.

The causality of biosemiosis is multi-level and “multi-directional”. From “below”, it subserves semiotic levels above by providing them with the potential meanings that are their semiotic wherewithal (as, for example, when semantic memory makes meaningful speech possible) or by entraining processes that will do so. Intra-level, biosemiosis constrains (that is, mediates, guides, co-ordinates, shapes and enables) cooperation and competition. From “above”, biosemiosis selectively constrains activity below (through entrained modulation of boundary conditions for the lower level activity). The “higher” the biosemiotic activity, the less frequent is its operation but the more general may be its consequences. Biosemiotic causation is a causality of constraint, not of mechanical necessitation. Given this, we might wonder at its effectiveness. But the efficacy of biosemiosis, while marvellous, is no mystery. Its wonders of nuanced, enabling constraint are accomplished through highly nuanced *entrainment* of higher-energy processes.⁵⁰

Thus we now have a criterion of the physical character of biosemiosis – its *causal signature* (as I have called it) – a reliable sign of its presence in a system. Where we find, in a system far-from-equilibrium, a physical stimulus prompting an initially tiny transduction of energy that subsequently produces a non-linearly increased *hierarchical* cascade of entrained physical sub-system consequences peculiarly or typically associated with that stimulus-type, there we have biosemiosis. I would stress this particularly in response to those who, while perhaps acknowledging the usefulness of the concept of biosemiosis, would treat it as nothing more than a useful (but, in principle, unnecessary) fiction or metaphor. In contrast to that view, I am arguing that the unique causal/physical signature of biosemiosis identifies it ontologically, and stamps it undeniably as a *natural kind* in good standing. (There are also of course semiotic-functional reasons for deeming it a natural kind. In living nature, all roads lead to (and from) semiosis.)

6. THE EVOLUTION OF BIOSEMIOSIS AND THE EVOLUTION OF LIFE

Biosemiosis is crucial at every level of living system. There is organelle biosemiosis, cellular biosemiosis, organ biosemiosis, organism biosemiosis, and ecological biosemiosis. At every level there is intra-level community biosemiosis. And between successive levels of living organization there is inter-level biosemiosis. The complexity

⁵⁰ K. Kull, T. Deacon, C. Emmeche, J. Hoffmeyer, & F. Stjernfelt, ‘Theses on Biosemiotics: Prolegomena to a Theoretical Biology’, in C. Emmeche & K. Kull (eds), *Towards a Semiotic Biology: Life is the Action of Signs*, London: Imperial College Press, 2011, pp. 25-41; K. Kull, C. Emmeche & D. Favareau, ‘Biosemiotic Research Questions’, in C. Emmeche & K. Kull (eds), *Towards a Semiotic Biology: Life is the Action of Signs*, London: Imperial College Press, 2011, pp. 67-90.

of organisms thus requires not only that there be intra-level and inter-level *sensitivity* to signs, but that there be inter-level and intra-level *production* of signs. Given my discussion above of the need for energy-efficiency in biosemiosis, and given that biological systems (and their sub-systems) produce signs at least partly to benefit themselves (that is, to maintain their own viability), it is important that producing the sign not too much deplete their resources (since in general the cost of sign-production needs to be commensurate with the benefits to be gained).

As Sharov and other biosemioticians argue, nature's "invention" of biosemiosis makes possible all of life. This invention had three main stages: first, the emergence (through processes of system self-organization) of the distinctive low-initial-energy causality of primitive semiosis, second, emergence of hierarchically complex interpretive systems; and third, emergence of proper signs and the ability of living systems to (conceptually) model potential responses and to evaluate the models rather than directly testing an interpretation through action. Because living systems and their living sub-systems necessarily function far-from-equilibrium, they must continually sample and assess the signs afforded by their *umwelts*, and appropriately respond to them to modulate their trajectories and maintain their viability as living systems in the face of disturbances which inevitably occur in this dynamic edge-of-chaos regime. Here, where small perturbations can produce potentially destructive non-linear consequences, it is important for living systems to be able not only to monitor and respond to potential dangers, but also to *anticipate* them. This too is among the functions (and the epistemological achievements) of biosemiosis (see section 7 below).

It is now well understood that all biological evolution is *co*-evolution. However, within every level of living process, and between immediately successive levels of living hierarchy – from the sub-cellular all the way through to complex ecologies – living systems are essentially *inter*-signifying. Nuanced interactions between members of communities (whether of organelles, or cells, or conspecific organisms, or multiple species in an ecological system) are mediated by and depend upon biosemiosis. Indeed, it is biosemiosis that makes possible their *co*-viability. Given that cooperative and competitive interactions depend upon biosemiosis, and that evolutionary developments involve changes in these interactions, it is clear not only that *co*-evolution is at least partly biosemiotic in its causes and its consequences, but also that biosemiosis and living systems have *co*-evolved.

Let us turn now to the evolution of nature's epistemological achievements: tracing (conjecturally, and very generally) the natural sequence of emergence (through semiosis) of intentionality, anticipation, sensation and perception, memory and

learning, pre-conceptual and conceptual knowledge, complex communication, thought, and understanding.

7. HOW BIOSEMIOSIS MAKES COGNITION, KNOWING, AND OTHER EPISTEMOLOGICAL ACHIEVEMENTS POSSIBLE

(a) *Intentionality and **umwelt** emerge with the emergence of semiosis*

We should start at the beginning. Epistemologically, what may we say of a self-maintaining, self-reproducing, autocatalytic, polymeric system of the sort Sharov discusses? It has a minimal repertoire of sensitivity to a very few primitive signs. It would be an exaggeration to deem this sensitivity *sensory*, and an even greater exaggeration to call it *perceptual*, as the system has no sensory or perceptual subsystem(s). Rather, its responsiveness to signs seems to rely on a few specific forms of *irritability* of its enclosing membrane. Each form of irritability is specific to a particular environmental sign that “triggers” a particular chemical response (the *interpretant*) within the system. However, it is in this very specificity that its *intentionality* consists. Intentionality requires neither perception (properly so-called) nor consciousness nor higher-level thought. Its reality is not mysterious, but is causal/functional: it is the “for-the-system-ness” of the causation that is characteristic of semiosis. The natural emergence of intentionality is none other than the emergence of this causal/functional “for-the-system-ness”; and with respect to an emergent causal/functional semiotic “repertoire” it is the emergence of an *umwelt*. Viewed causally and functionally, “for-the-system-ness” is prospective and anticipatory.

(b) *Semiosis is essentially anticipatory*

The “for-the-system-ness” of semiotic causation pertains to the system’s continuance and potentiality; it is thus essentially prospective. And inasmuch as it is prospective, semiosis is essentially anticipatory. (See also 7(c) and 7(d) below.) Although it might seem that conceptual modelling – that is, representation, and/or representational memory – would be required for anticipation, I do not think either is necessary (see also 8(b)(3) below). Indeed, I think *all* semiosis is anticipatory, inasmuch as the meaning imputed (whether explicitly or implicitly, conceptually or non-conceptually, in reflection or in action) is always, even if only implicitly, in some measure *prospective*. The upshot of all semiosis is, in effect, *Now do this*, or, at higher levels of cognition, *Now think this*, where the mode of thought may be further glossed and inherently involves valuation; and where in each case, that which is to be done or thought is either to continue, begin, or complete an activity or project. Biosemiosis is thus prospective in

three biologically fundamental ways: (1) as anticipation of either the beginning, continuance or completion of an activity or project; (2) in its potential for contributing to system continuance and viability; and (3) in its evolutionary role with respect to a system's reproduction and contribution to a viable lineage. (1) and (2) pertain to all semiotic systems, since the meaning of a sign (for the system) will consist in activity *subsequent* to the sign which prompted it. In that time gap (however long or short) circumstances may or may not have changed; the activity thus needs to be apt for those *subsequent* circumstances, and thus needs to anticipate their trajectory if it is to avoid being unproductive or counter-productive. And with regard to (2) and (3), natural selection will have favoured actions which are more likely to be apt for those changed circumstances and which in that sense better anticipate their trajectory.

(c) *Sensitivity, perception, knowledge, memory*

Does a primitive autocatalytic semiotic system have knowledge? Certainly it has no declarative or propositional knowledge; but may we say at least that it *knows how* to respond to a few signs, or that it knows how to maintain and reproduce itself? I would prefer to say it doesn't know how *not* to do those things: the sign, as causal irritant, simply *triggers* the particular response. The system's specific irritabilities, and the resultant response-triggerings, are epistemological achievements of sorts, but just as I would resist describing them as sensitivity or perception, I would hesitate also to call them cognition or knowing. Nonetheless, the system's epistemological achievement is considerable; for (as I have argued) its emergent causality constitutes primitive chemical semiosis, and thus intentionality, and (as repertoire or habit) the formation of an *umwelt*.

However, because spontaneously emergent "complexification" – that is, *self-organization* – is possible for systems at the edge of chaos,⁵¹ self-maintaining, self-reproducing *hierarchical* semiotic systems eventually will have emerged. In time, some would develop semiotic sub-systems facilitating more nuanced responses to a larger repertoire of signs – *autopoietic, living* systems (autopoiesis is Maturana and Varela's biological criterion for a living organism: an autopoietic system is not only self-stabilizing and self-maintaining, but it makes the *sub*-systems that it needs *in order to* make its sub-systems and to maintain its own viability).⁵² As biosemiotic responsiveness becomes more nuanced, *sensitivity* replaces mere irritability; and as organisms evolve sub-systems enabling semiotic sensitivity, sensation and perception emerge in nature.

⁵¹ See e.g. Goodwin, *op. cit.*; Solé & Goodwin, *op. cit.*; and Kauffman, *op. cit.*

⁵² Maturana & Varela, 1980 and 1987.

But at what level of nature or at what stage of evolution does *knowledge* begin? Does the Venus fly trap *know how* to catch insects? Or does it just *do* it (in a semiotically mediated way) without needing to *know* how? If, like Maturana and Varela, we were to redefine *knowing*, so as to say with them that ‘living is knowing’,⁵³ we would attribute knowledge to the Venus fly trap. Perhaps there is little harm in this, but I’m not persuaded it is necessary. My own view is that the fly trap does not *need* to know how to trap insects, because it cannot *prevent* itself from trapping them. However, if it were able to *modulate* its response in light of circumstances, I would see no problem in saying it knows how to catch insects. At any event, theoretical orientation will determine where we deem knowing to begin in nature. Likewise, whether we hold it to require capacity for memory. My own view on this is that memory (properly, and not merely figuratively, so-called) may be unnecessary for knowing-how, since inherited instincts may constitute an *ersatz* “memory” sufficient for at least some of the abilities describable as *knowing-how* and for the biosemiotic responsiveness they rely on.

However, propositional knowledge, I think, does require appropriate systems of memory – in addition to the foregoing capabilities. But is that enough – or is the semiotic sophistication of language also required? Philosophers once assumed so, because they saw no other way of incorporating *meaning* into cognition. Since we now have the concepts of biosemiosis and *umwelt* for this purpose, we are no longer hamstrung in that way, so let us explore which epistemological achievements are possible pre-linguistically and which are not.

Another name for propositional knowledge is *knowing-that* (for example, knowing that one is hungry). It is also termed declarative knowledge. We should not assume from this that by definition it requires language. However, it does seem to call for possession of relevant concepts. In turn, possession of concepts seems to require sensory discrimination (that is, interpretation of signs) informed by memory. Does the dog know it is going to be taken for a walk? It recognises the lead and collar in your hand and is excited – we probably suppose that it is anticipating a walk, which anticipation we attribute to its memory of similar past occasions when the lead and collar signified that an enjoyable walk was imminent. But does the dog have the *concepts* of a lead, a collar, a walk, or imminence? Does it need *these* particular concepts in order to know that it is going for a walk? It recognizes the lead, but perhaps not *as* what we mean by a dog’s lead. Our concept is no part of the dog’s *umwelt*, and neither is our understanding of ‘going for a walk’. But while we cannot avoid using concepts from our own *umwelt* in describing the *umwelt* of the dog, this

⁵³ *Ibid.*

need not be to impute our concepts or our particular recognitions to the dog. Nonetheless, the dog's behaviour does betoken recognition of signs, despite our inability to characterize its recognitions in "dog-concepts". Uexküll's central insight was that we can conjecturally posit a systematic functional/structural interpretation of the dog's behaviour and *umwelt*, in terms of (conjectured) similarities with, and differences from our own. With regard to the dog's knowledge in this particular example, perhaps we should simply say it recognizes or knows (in its *own* way) *what* is going to happen. (We might call this form of knowledge *knowing-what*, or more generally *knowing-wh...*) And with regard to its semiotic achievement, that it recognizes (knows, in its *own* way) what the signs are signs *of*.

However, let us suppose that on this occasion the dog is disappointed – no walk ensues. After several such disappointments, might the dog eventually recognize – come to know – *that* it is not going for a walk? The appearance of what we refer to as 'the dog's lead' is a *sign* for the dog of what we term 'the imminence' of what we understand as 'our taking the dog for a walk'. It is so because the dog has learned the significance of the appearance of the lead from its previous association with being taken for a walk soon after. This semiotic learning is the basis of the dog's knowledge, whether this be knowing-*how*, knowing-*wh*, or knowing-*that*. But as we know, and as perhaps the dog comes to know, signs are not always reliable, and on occasion may lack their usual significance. For the dog, this might prompt a more nuanced recognition of signs: a clever dog might learn to recognise *when* appearance of the lead betokens a walk and when it doesn't. In this case it may on occasion be correctly said to know that despite the lead's appearance, there will be no walk.

Here I have been speaking again of *anticipation*, but in this case anticipation mediated by memory. Earlier I discussed three biologically fundamental ways in which biosemiosis may be deemed anticipatory: (1) constitutively, as prospective activity or project; (2) in potentially contributing to system continuance and viability; and (3) through evolution, with respect to a system's reproduction and contribution to a viable lineage. However, cognitively higher-level biosemiosis may be anticipatory in either of two further ways: either (4) in the manner of a nuanced production-system (an algorithmic or quasi-algorithmic system of "rules" for action, nuanced to differences in sensory input, and in that sense selectively anticipating possibilities); or (5) in the familiar manner of representational-conceptual modelling of possibilities and their prospective implications. Both (4) and (5) of course rely on appropriate biosemiotic subsystems of memory.

(d) *Biosemosis and epistemological values*

It may seem odd that all knowledge, even knowledge of the past, is always, in some measure, semiotically prospective and anticipatory. However, we should bear in mind that epistemology itself is always a system of *values*, and as such is *normatively* prospective. Regard for the epistemological values of truth, systematic consistency, evidence, likelihood, heuristic fruitfulness, testing of theory and conjecture, cogency of reasoning – in short, regard for justification – has consequences for how we should be and for what we should do and think, now and in the future. But what is most illuminating here is that these values have emerged, both naturally and culturally, from developments of the inherent valuational character of biosemiosis itself. The inherently prospective, anticipatory character of biosemiosis is, *eo ipso*, its valuational character also. This is because the causal character of biosemiosis is the foundation also of its *functional* character – that whereby system production, maintenance and viability are achieved – and functionality is inherently a value-concept as well as a causally descriptive concept. In brief, survival is a value for living systems (even if only one value among others) and is achievable only through biosemiosis. (For even when an organism seems to survive through “dumb luck”, the integrity and functioning of its organic sub-systems were maintained not by “dumb luck” but by biosemiotic communication and semiotically entrained processes of modulation.) This is explicitly acknowledged by virtually all biosemiotic theorists. As the complexity of living systems evolved, so too their causal-functional systematicity became more complex, with the emergence of new epistemological functions essentially involving new forms of valuation (such as evaluations of likelihood, costs versus benefits, interpretive evaluation of linguistic meaning, and assessment of truth or falsity) that are the “point” of their emergent complex causality.

(e) *Nuanced epistemological achievements, and nuanced epistemology*

We take it for granted that epistemology concerns a field of highly nuanced interpretation and evaluation; however the emergence of nuance is very much an evolutionary development. Primitive semiosis was simply a matter of “triggered” activity, not one of nuanced discrimination or degree. Nuanced evaluation emerged semiotically in sensitivity, perceptual discrimination, informed judgment, understanding and wisdom: all of them passages in the emergence of semiotic appreciation of *systemic* relationship – systemic because all nuance is essentially systemic. (Otherwise, it would not be nuance, but merely a difference which *made no*

difference.⁵⁴ All systems consist of relationships of enabling constraint: this is their essential functional character – and all systems, *qua* systems, are construed functionally. What is enabled in a system is nuanced by systemic relationships of operative constraint; for enablement requires that a “trajectory” of the system, or of a sub-system, be constrained so that it is sufficiently robust and does not prematurely dissipate, and so that its contraries or opponents cannot yet prevail.)

Appreciation – which is the name I shall give to this class of epistemological achievements (some “lower”, some “higher”) – is always nuanced and a matter of degree; it always pertains to features of systematicity, and is achieved through more or less systematic evaluation. It is through appreciation of systematicity that epistemology itself is possible, since epistemology is evaluatively nuanced to ‘differences that [systemically] make a difference’ cognitively. However, epistemology is both a field of inquiry *and* (as here) a subject-matter of that very field. There is no “view from nowhere” in this field; our understanding of our understanding is made possible by our *noetic umwelt*, and this understanding in turn may make possible further emergent meaning, and, through this, further development of our *noetic umwelt* – a view not from nowhere, but from *our human* noetic achievements and constraints. What makes these understandings possible is, ultimately, biosemiosis. In short, our understanding is systemically constrained biosemiotically, and through our biosemiotically subserved semiotic enculturation. But this does not mean we are “trapped” by current limitations of this *umwelt*; for like every complex system, it is a system of *enabling* constraint, and like every *emergent* system, it is emergently *self-organising*, which in this context means that it yields *new* understandings, new appreciations, new illuminations and new insights that both critique and extend that *umwelt*, and which may even facilitate its transformation or transcendence.⁵⁵

8. CONCLUSION

(a) *Summary of my argument*

I have argued that it is through semiosis that nature makes knowledge, and indeed all epistemological achievements, possible; and that it is specifically biosemiosis which makes possible the emergent hierarchical self-organization of all forms of life, and

⁵⁴ Cf. G. Bateson, *Steps to an Ecology of Mind: Collected Essays in Anthropology, Psychiatry, Evolution, and Epistemology*, Chicago: University Of Chicago Press, 1972.

⁵⁵ On cognitive transformation, see *esp.* R. Kegan, *In Over Our Heads: The Mental Demands of Modern Life*, Cambridge, Mass: Harvard University Press, 1994, and R. Kegan, ‘What “Form” Transforms? A Constructive-Developmental Perspective on Transformational Learning’, in J. Mezirow and Associates (eds), *Learning as Transformation: Critical Perspectives on a Theory in Progress*, San Francisco: Jossey-Bass, 2000.

through this the living systems and abilities which underlie those epistemological achievements. Central to my argument has been an examination of the distinctive causal/functional character of biosemiosis which I have identified as its “signature” – a defining *sign* of its presence and operation. Specifically, I aimed to show how nature’s “inventions” of non-linear causation and cybernetic process-modulation led to the emergence of *semiotic* systems at ‘the edge of chaos’, whose responsiveness to *ultra-low-energy* signals radically enhances their viability by instigating a non-linear cascade of adaptive activity peculiarly associated with the signal type, and how this made possible the emergence of *hierarchically* structured, *biosemiotically* modulated, self-organising living systems. In light of that discussion I have essayed a moderately detailed, if inevitably somewhat speculative understanding of the causal/functional roles of biosemiosis in epistemological emergence and cognitive evolution. My entire argument is naturalistically conceived in a pragmatic spirit which acknowledges that the inquirer, the process of inquiry, and its outcomes are inevitably implicated in the subject-matter of inquiry. Like all fields of inquiry, epistemology inevitably constitutes a *noetic umwelt*; but in considering itself reflexively (as in the foregoing discussion) and submitting itself to pragmatic testing, it too is part of the long and wonderful process of natural/cultural emergence through which life raises itself by its own semiotic “bootstraps”.

(b) *Three objections forestalled*

That, in essence, was my positive argument. However, here I shall complete my argument by forestalling three possible objections based on misconstruals of my position.

(1) First, I want to stress my disavowal of ontological and epistemological reductionism, and to respond to the possible objection that despite that disavowal my account is ultimately reductionist. I am not arguing that life or biosemiosis reduces to the physically constituted causal patterning which is the latter’s causal signature: rather, I hold that “signature” to be the distinctive *sign* of the *emergent systemic-functional self-organization* which is biosemiosis. My ontological perspective is not that of reductive physicalism; rather, I hold emergent process-organization to be ontologically real and irreducible. With Bickhard and Campbell,⁵⁶ I hold emergent causality – emergent enabling constraint – to be the hallmark of all ontologically significant emergence. In the natural emergence of semiosis, emergent causality makes possible naturally emergent *function* (and dysfunction) as Bickhard and

⁵⁶ Bickhard & Campbell, *op. cit.*

Campbell note.⁵⁷ Naturally emergent functional organization is not reducible to the physical processes subserving it, because it essentially constitutes ontologically emergent forms of constraint (systemic boundary conditions) on the trajectories of subserving physical processes.⁵⁸ Neither is it reducible to forms of lower-level functional organization on which its emergence depends, since it constrains at least some of that lower-level organization.⁵⁹ Thus I am not proposing or presupposing any sort of ontological reductionism. Furthermore, I concur with the view of biosemiotic theorists, and of many – possibly most – biologists, that the life sciences would be impossible were they to eschew all functional description and functional explanation, and that any explicit attempt to do so inevitably leads either to implicit functional assumptions or to incoherence. Thus, in holding that emergent natural function achieved through emergent causality is irreducible to lower-level function or lower-level causality, I am also repudiating epistemological reductionism in the life sciences. Given the foregoing, I hope it is clear that in no way am I proposing a reductionist epistemology either.

(2) Second, I want to clarify my position regarding the concepts of life and *artificial* life, viewed from a biosemiotic perspective, by anticipating and answering the following possible objection. Suppose it were objected that my view of biosemiotic theory entails that an inexpensive personal computer, since it has an hierarchical functional architecture, and is systemically responsive to minute inputs of energy, which its programming may allow to systemically entrain a non-linear cascade of hierarchically realized processes, therefore must be deemed (absurdly) a *living being* since its operation exhibits the distinctive causal “signature” of biosemiosis. The basis of my response to this alleged entailment is that it completely misrepresents my position. Biosemiosis occurs only in the dynamic regime of the ‘edge of chaos’ – this being crucial for the forms of *emergent* self-organization by which it is embodied. Everyday computers are not of this sort, and, to my knowledge, no human-engineered computers of this sort exist. If they did or do exist, they would be very different machines from those with which we are familiar. The whole point and nature of biosemiosis is its production of *emergent self-organization* of the peculiar and complex type I have described. It is not that biosemiosis simply relies on prior such emergence; rather, it is its nature also to produce the systems which *produce* it. This is the nature of life itself. If this were achieved by a specialized computer adapted to, and functioning at the edge of chaos, then this in my view would indeed be semiosis

⁵⁷ *Ibid.*

⁵⁸ See e.g. Deacon, *op. cit.*, esp. Chs 5&6.

⁵⁹ Deacon, *op. cit.*

properly-so-called. (Note too that in *these* circumstances, the argument of Searle's "Chinese-Room" thought-experiment – to the effect that a (syntactically) rule-governed computer cannot achieve understanding⁶⁰ – would not apply, since Searle's argument is implicitly restricted to systems in which self-organized emergence *cannot* occur.) And if an emergently self-organizing computer, and/or its subsystems, were able to maintain and reproduce itself/themselves and thereby establish a semiotic community, I see no reason for denying such systems the status of *artificial life* – particularly as their functioning would exemplify *autopoiesis*. This is not in the least a problem for my account, and is a very different scenario from that adverted to by my hypothetical objector.

(3) Finally, there is an argument of von Neumann, elaborated by Howard Pattee with regard to its significance for the physics of biosemiosis,⁶¹ which might be thought to invalidate two aspects of my account of biosemiosis – viz. non-representational biosemiotic anticipation, and the first emergence of reproduction in primitive biosemiotic systems. Von Neumann's argument is to the conclusion that necessarily (i.e. as a matter of logic) for a system to be capable of self-replication and open-ended evolution it must be able to adequately model its own systems and their functioning symbolically. Pattee elaborates on the argument's implications for biological self-repair and reproduction, and for the establishment of evolutionary lineages.⁶² I will not sketch either argument, as, given their respective presuppositions, I accept both. What I do not accept is that their presuppositions are apt for *all* biosemiotic, reproducing systems. Essentially (although this is not made explicit in either account) the presuppositions of both arguments pertain only to *autopoietic* self-reproduction; however, natural autopoietic systems are in fact only a proper *sub-class* of biosemiotic systems. Autopoiesis emerges in nature only at higher levels of complexity than do primitive semiosis and non-representational biosemiosis. Von Neumann's and Pattee's arguments apply only to systems whose reproduction *is unaided by their environments* (except insofar as their environments supply energy and raw materials) – in short, autopoietic systems. They do not acknowledge that in primitive cases, in favourable environments, essential sub-tasks involved in reproduction might be "performed" by a system's environment in the absence of semiotic modelling of that which is reproduced. The simplest such sub-tasks might be splitting-off of sub-systems and/or capture of other systems or (split-off) sub-systems, where the splitting is caused by environmental buffeting or chemically produced fracture, and capture is fortuitous

⁶⁰ J. Searle, 'Minds, Brains and Programs', *Behavioral and Brain Sciences*, vol. 3, no. 3, 1980, pp. 417-457.

⁶¹ H.H. Pattee, 'The Physics of Symbols and the Evolution of Semiotic Controls', in D. Favareau (ed.), *Essential Readings in Biosemiotics*, Springer Netherlands, 2009, Ch.17.

⁶² *Ibid.*

or mediated by natural currents or fields of attraction. Environmental perturbation, whether mechanical, electromagnetic or chemical, might also alter processes internal to a system. Environmentally produced alterations of any of these types might need to happen many times before a biosemiotically mediated system was fortuitously duplicated, but given a sufficiently rich (and perhaps changing) environment of polymeric activity, and given the role of semiosis in maintenance of (sub-)system viability, this need not be thought implausible. Indeed, it seems to me most plausible. (What seems to me *implausible* is the assumption that reproduction was *impossible* prior to the emergence of complex symbolic codes necessary for modelling system reproduction and the intricately nuanced mediatory functioning of such modelling. For this would seem to make the natural emergence of autopoiesis scarcely less than a miracle.) It is salutary to remember here that no complex system – and thus no semiotically mediated system – is ever adequately understood apart from its interactions with its environment.

ACKNOWLEDGEMENTS

I particularly wish to thank two groups of colleagues. First, the members of the Joseph Needham Complex Processes Research Group chaired by Arran Gare at Swinburne University, for the lively environment of ongoing research and discussion that prompted my line of thought, and for their encouraging comments on an earlier version of these ideas that I presented to the group some years ago; with special thanks to Glenn McLaren and Paul Healy, for their comments on the penultimate draft of the present paper. Second, my thanks to Diana Bossio and the members of the Humanities, Arts, and Social Sciences writing group Diana organized at Swinburne in 2012, for their invaluable collegial support and constructive criticism of the present paper as it was being written. Additionally, I am grateful to an anonymous reviewer of this journal for critical comments that have led me to clarify my argument (I hope) at several places.

Philosophy and Cultural Inquiry
Swinburne University of Technology
mdix@swin.edu.au

BIBLIOGRAPHY

- Andersen, P.B., Emmeche, C., Finnemann, N.O. & Christiansen, P.V. (eds.), *Downward Causation: Minds, Bodies and Matter*. Aarhus: Aarhus University Press, 2000.
- Aristotle. *Aristotle's Metaphysics*. Trans. and ed. W.D. Ross. Oxford: Clarendon Press, 1924.
- Aristotle. *Aristotle: De Anima, Books II and III (with passages from Book I)*. Trans. with Introduction and Notes by D.W. Hamlyn. Oxford: Clarendon Press, 1968.
- Barbieri, M. *The Organic Codes. An Introduction to Semantic Biology*. Cambridge: Cambridge University Press, 2003.
- Barbieri, M. 'Life is Semiosis'. *Cosmos and History*, vol. 4, no.1-2, 2008, pp. 29-52.
- Bateson, G. *Steps to an Ecology of Mind: Collected Essays in Anthropology, Psychiatry, Evolution, and Epistemology*. Chicago: University Of Chicago Press, 1972.
- Bickhard, M.H. & Campbell, D.T. 'Emergence'. In P.B. Andersen, C. Emmeche, N.O. Finnemann, & P.V. Christiansen (eds), *Downward Causation: Minds, Bodies and Matter*. Aarhus: Aarhus University Press, 2000, pp. 322-348.
- Cohen, J. & Stewart, I. *The Collapse of Chaos: Discovering Simplicity in a Complex World*. London & New York: Penguin, 1995.
- Deacon, T.W. *Incomplete Nature: How Mind Emerged from Matter*. New York: W.W. Norton & Company, 2012.
- Emmeche, C., Koppe, S. & Stjernfelt, F. 'Levels, Emergence, and Three Versions of Downward Causation', in P.B. Andersen, C. Emmeche, N.O. Finnemann, & P.V. Christiansen (eds), *Downward Causation: Minds, Bodies and Matter*. Aarhus: Aarhus University Press, 2000, pp. 13-34.
- Emmeche, C. and Kull, K., eds. *Towards a Semiotic Biology: Life is the Action of Signs*. London: Imperial College Press, 2011.
- Fraser, J.T. 'The Extended Umwelt Principle: Uexküll and the Nature of Time'. *Semiotica*, no. 134, 2001, pp. 263-273.
- Gare, A. 'Systems Theory and Complexity: Introduction', *Democracy and Nature*, vol. 6, no. 3, 2000, pp. 327-339.
- Goodwin, B. *How the Leopard Changed Its Spots: The Evolution of Complexity*. London: Phoenix, 1995.
- Hoffmeyer, J. *Signs of Meaning in the Universe*. Bloomington: Indiana University Press, 1996.
- Hoffmeyer, J. *Biosemiotics. An Examination into the Signs of Life and the Life of Signs*. Scranton PA: University of Scranton Press, 2008.

- Hoffmeyer, J. 'Biology is Immature Biosemiotics', in Emmeche, C. and Kull, K. (eds), *Towards A Semiotic Biology*, London: Imperial College Press, 2011, pp. 43-65.
- Husserl, E. *Ideas Pertaining to a Pure Phenomenology and to a Phenomenological Philosophy—Second Book: Studies in the Phenomenology of Constitution*, trans. R. Rojcewicz and A. Schuwer. Dordrecht: Kluwer, 1989.
- Kant, I. *Critique of Pure Reason*. Revised 2nd edn. Trans. N. Kemp Smith, with a new Introduction by H. Caygill. Basingstoke: Palgrave Macmillan, 2003.
- Kant, I. *Prolegomena to any Future Metaphysics*. Revised edn, trans. and ed. G. Hatfield. Cambridge: Cambridge University Press, 2004.
- Kauffman, S.A. *The Origins of Order: Self-Organisation and Selection in Evolution*. New York: Oxford University Press, 1993.
- Kegan, R. *In Over Our Heads: The Mental Demands of Modern Life*, Cambridge, Mass: Harvard University Press, 1994.
- Kegan, R. 'What "Form" Transforms? A Constructive-Developmental Perspective on Transformational Learning.' In J. Mezirow and Associates (eds), *Learning as Transformation: Critical Perspectives on a Theory in Progress*. San Francisco: Jossey-Bass, 2000.
- Kull, K. 'Jakob von Uexküll: An introduction'. *Semiotica*, no. 134, 2001, pp. 1-59.
- Kull, K., Deacon, T., Emmeche, C., Hoffmeyer, J. & Stjernfelt, F. 'Theses on Biosemiotics: Prolegomena to a Theoretical Biology'. In C. Emmeche & K. Kull (eds), *Towards a Semiotic Biology: Life is the Action of Signs*. London: Imperial College Press, 2011, pp. 25-41.
- Kull, K., Emmeche, C., & Hoffmeyer, J. 'Why Biosemiotics? An Introduction to Our View on the Biology of Life Itself'. In C. Emmeche & K. Kull (eds), *Towards a Semiotic Biology: Life is the Action of Signs*. London: Imperial College Press, 2011, pp. 1-21.
- Kull, K., Emmeche, C. & Favareau, D. 'Biosemiotic Research Questions'. In C. Emmeche & K. Kull (eds), *Towards a Semiotic Biology: Life is the Action of Signs*. London: Imperial College Press, 2011, pp. 67-90.
- Lettvin, J.Y., Maturana, H.R., McCulloch, W.S., & Pitts, W.H. 'What the frog's eye tells the frog's brain'. In W. C. Corning & M. Balaban (eds), *The Mind: Biological Approaches to its Functions*. New York: Interscience Publishers, 1968, pp. 233-58.
- Lewin, R. *Complexity: Life at the Edge of Chaos*. 2nd edition. Chicago and London: The University of Chicago Press, 1999.
- Maturana, H. & Varela, F. *Autopoiesis and Cognition: the Realization of the Living*. R.S. Cohen and M.W. Wartofsky (eds), *Boston Studies in the Philosophy of Science*, vol. 42. Dordrecht: D. Reidel Publishing Co, 1980.

- Maturana, H. R. & Varela, F. J. *The tree of knowledge: The biological roots of human understanding*. Boston: Shambhala Publications, 1987.
- Millikan, R.G. *Language, Thought and Other Biological Categories*. Cambridge, MA: MIT Press, 1984.
- Nagel, T. 'What is it like to be a bat?' *Philosophical Review*, vol. 83, no. 4, 1974, pp. 435-50.
- Neuman, Y. 'Why Do We Need Signs in Biology?' In C. Emmeche & K. Kull (eds), *Towards a Semiotic Biology: Life is the Action of Signs*. London: Imperial College Press, 2011, pp. 195-209.
- O'Neill, R.V., DeAngelis, D.L., Waide, J.B. & Allen, T.F.H. *A Hierarchical Concept of Ecosystems*. Monographs in Population Biology, no. 23. Princeton, NJ: Princeton University Press, 1986.
- Pattee, H.H. 'Evolving Self-Reference: Matter, Symbols, and Semantic Closure', *Communication and Cognition*, vol. 12, 1995, pp. 9-27.
- Pattee, H.H. 'The Physics of Symbols and the Evolution of Semiotic Controls', in D. Favareau (ed.), *Essential Readings in Biosemiotics*. Springer Netherlands, 2009, Ch.17.
- Peirce, C.S. *Collected Papers of Charles Sanders Peirce*, (8 vols), C. Hartshorne, P. Weiss & A.W. Burks (eds). Cambridge, Mass.: Belknap Press, 1931-1958.
- Peirce, C. S. *The Essential Peirce, Selected Philosophical Writings, Volume 1 (1867-1893)*. N. Houser & C.J.W. Kloesel (eds). Bloomington and Indianapolis, IN: Indiana University Press, 1992.
- Peirce, C. S. *The Essential Peirce, Selected Philosophical Writings, Volume 2 (1893-1913)*. Peirce Edition Project (eds). Bloomington and Indianapolis, IN: Indiana University Press, 1998.
- Piaget, J. *The Construction of Reality in the Child*. New York: Basic Books, 1954.
- Piaget, J. *The Principles of Genetic Epistemology*. New York: Basic Books, 1972.
- Plato *The Republic of Plato*. Trans. A. Bloom, with notes and an interpretive essay. New York: Basic Books, 1968.
- Plotkin, H. *Darwin Machines and the Nature of Knowledge*. Harmondsworth: Penguin, 1993.
- Rorty, R. *Philosophy and the Mirror of Nature*. Princeton, NJ: Princeton University Press, 1979.
- Sacks, O. *Awakenings*. London: Duckworth; New York: Doubleday, 1973.
- Sacks, O. *The Man Who Mistook His Wife for a Hat*. London: Duckworth; New York: Summit Books, 1985.

- Sacks, O. *An Anthropologist on Mars*. New York: Alfred A. Knopf; London: Picador, 1995.
- Sacks, O. *The Island of the Colorblind*. New York: Alfred A. Knopf; London: Picador, 1996.
- Salthe, S.N. *Evolving Hierarchical Systems: Their Structure and Representation*. New York: Columbia University Press, 1985.
- Salthe, S.N. *Development and Evolution: Complexity and Change in Biology*. Cambridge, MA: MIT Press, 1993.
- Schutz, A. *The Phenomenology of the Social World*. Evanston, IL: Northwestern University Press, 1967.
- Searle, J. 'Minds, Brains and Programs', *Behavioral and Brain Sciences*, vol. 3, no. 3, 1980, pp. 417-457.
- Sharov, A. 'The Origin and Evolution of Signs', *Semiotica*, no. 127, 1999, pp. 521-535.
- Sharov, A. 'Umwelt theory and pragmatism', *Semiotica*, no. 134, 2001, pp. 211-228.
- Solé, R. & Goodwin, B. *Signs of Life: How Complexity Pervades Biology*. New York: Basic Books, 2000.
- Sutrop, U. 'Umwelt, Word and Concept: Two Hundred Years of Semantic Change'. *Semiotica*, no. 134, 2001, pp. 447-462.
- Uexküll, J. von, *Theoretical Biology*. New York: Harcourt, Brace & Co, 1926.
- Uexküll, J. von, 'A Stroll Through the Worlds of Animals and Men: A Picture Book of Invisible Worlds', in *Instinctive Behavior: The Development of a Modern Concept*, ed. and trans. Claire H. Schiller. New York: International Universities Press, Inc., 1957, pp. 5-80.
- Uexküll, J. von, 'The theory of meaning'. *Semiotica*, no. 42, 1982, pp. 25-82.
- Uexküll, J. von, 'An introduction to Umwelt'. *Semiotica*, no. 134, 2001, pp. 107-110.
- Uexküll, J. von, *A Foray into the Worlds of Animals and Humans, with a Theory of Meaning*. Trans. Joseph D. O'Neil. Minneapolis: University of Minnesota Press, 2010.
- Uexküll, T. von, 'The sign theory of Jakob von Uexküll'. In: Krampen et al. *Classics of Semiotics*. New York: Plenum, 1987, pp. 147-179.
- Uexküll, T. von, 'Introduction: The sign theory of Jakob von Uexküll'. *Semiotica*, no. 89, 1992, pp. 279-315.
- Weaver, W. 'Science and Complexity'. *American Scientist*, vol. 36, 1948, pp. 536-544.