

MATHEMATICS, NARRATIVES AND LIFE: RECONCILING SCIENCE AND THE HUMANITIES

Arran Gare

ABSTRACT: The triumph of scientific materialism in the Seventeenth Century not only bifurcated nature into matter and mind and primary and secondary qualities, as Alfred North Whitehead pointed out in *Science and the Modern World*. It divided science and the humanities. The core of science is the effort to comprehend the cosmos through mathematics. The core of the humanities is the effort to comprehend history and human nature through narratives. The life sciences can be seen as the zone in which the conflict between these two very different ways of comprehending the world collide. Evolutionary theory as defended by Schelling developed out of natural history, but efforts have been made to formulate neo-Darwinism through mathematical models. However, it is impossible to eliminate stories from biology. As Stuart Kauffman argued, mathematical models attempt to pre-state all possibilities, but in evolution there can be adjacent possibles that can be embraced by organisms but cannot be pre-stated. To account for such actions it is necessary to tell stories. Mathematics provides analytic precision allowing long chains of deductions, but tends to deny temporal becoming and cannot do justice to the openness of the future, while narratives focus on processes and events, but lack exactitude that would provide precise deductions and predictions. In advancing mathematics adequate to life, Robert Rosen argued that living beings as anticipatory systems must have models of themselves, and strove to develop a form of mathematics able to model life itself. It has been convincingly argued that narratives are central to human self-creation and they are lived out before being explicitly told. Their models of themselves are first and foremost, stories or narratives. If this is the case, might not living beings as biological entities be characterized by proto-stories or narratives in their models of themselves? Biosemiotics, largely inspired by C.S. Peirce, provides a bridge between mathematical and narrative comprehension, conceiving them as different forms of semiosis. The study of life through biosemiotics could reveal how mathematics and narratives can be understood in relation to each other. This could then have implications for how we understand science and the humanities and their relationship to each other. In this paper I will examine work in theoretical biology that might advance these efforts.

KEYWORDS: Mathematics; Narratives; Complexity theory; Semiotics; Biosemiotics; Stuart Kauffman; Robert Rosen; C.S. Peirce; A.N. Whitehead

THE DOMINANT WORLD-VIEW

The scientific revolution of the Seventeenth Century was above all a revival of Pythagoreanism in opposition to Aristotelian and Nature Enthusiast philosophies of nature, and more broadly, and this has only relatively recently been understood, in opposition to the humanities (Toulmin, 1994). It was advanced through the development of new forms of mathematics, most importantly, analytic geometry and then the calculus. ‘Matter’ was reconceived to support this Pythagoreanism, as ‘brute and stupid’ – in opposition to the conception of matter promoted by the Nature Enthusiasts, as divine (Jacob, 2003). Hence, in Britain and France the New Philosophy, or ‘scientific materialism’, as Alfred North Whitehead called it in *Science and the Modern World* (1932), triumphed. This went along with the development of mechanistic explanations, explaining things by breaking them down to their components and explaining wholes in terms of these, as Francis Bacon and Thomas Hobbes had called for. Combining Pythagoreanism with reductionist explanations produced the mechanistic world-view. This was supplemented by the belief in God as clockmaker, providing the final cause to account for the order of natural machines. All purpose in the world was explained through God, who also created humans in his own image. This world-view was associated with Cartesian dualism or, following Hobbes, by characterizations of humans as very complex machines.

Leaping to the Nineteenth and Twentieth centuries, Darwinian evolutionary theory combined with genetics appeared to account for the organization of matter without the need to postulate a transcendent God. With Ludwig Boltzmann’s reductionist explanation of the second law of thermodynamics, and then the equation of negative entropy with information, identification of RNA and DNA, seen as encoding information, as the basis of genetics, life itself was reduced to biochemistry and information theory. Cognition was then characterized as receiving and processing information, and with the development of cybernetics, organisms were conceived as information processing cyborgs. The mind itself was mechanized (Dupuy, 2009), seen as mechanical processes, and as such, components of machines, ultimately for reproducing genes, or DNA. Societies were characterized in the same way, with economists playing the major role in this, using these more recent developments in biology to update their mechanistic model of *homo economicus*. Meanwhile in physics, more and more abstruse mathematical models were associated with the tacit acceptance of logical

positivism or even logical atomism, according to which, what matters in science is being able to make accurate predictions about what will be observed, not comprehending the nature of physical existence. The notion of inert matter was more or less abandoned, although there was and is still a tendency to assume that explanation requires identification of components and then to model their interactions, with elementary particle physics having a privileged position in science. With these developments, Pythagoreanism has retained its grip on mainstream science, and if anything, has been strengthened, even when materialism is abandoned (Gare, 2005). Reformulating physics through the concept of information, John Wheeler has argued that what we take to be things, or ‘its’, are constructions from ‘bits’ of information (Davies, 2010; Gare, 2020). This is identified as the scientific world-view, and is associated with ‘scientism’, the claim that only science and the ‘scientific method’ gives us genuine knowledge.

This is a very schematic history, but then all histories are schematic to some extent. They can’t include everything. And such histories are required to understand our present situation and orient us for creating the future. This schematic history can be situated as part of a longer history of European civilization. Friedrich Nietzsche complained about the ‘Egyptianism’ of philosophers, their aversion to acknowledge real change and becoming. As he put it in *Twilight of the Idols* (1968: 35)

There is ... their hatred of even the idea of becoming, their Egyptianism. They think they are doing a thing honour when they dehistoricise it, *sub specie aeterni*—when they make a mummy of it. All that philosophers have handled for millennia has been conceptual mummies; nothing actual has escaped their hands alive. They kill, they stuff, when they worship, these conceptual idolaters—they become a mortal danger to everything when they worship. Death, change, age, as well as procreation and growth, are for them objections—refutations even. What is, does not become; what becomes is not ... Now they all believe, even to the point of despair, in that which is.

This can be traced back to the influence of Parmenides, but Parmenides was spelling out the implications of Pythagoras. Nietzsche himself noted the role of mathematics and science dominated by mathematics in this Egyptianism. As he put it in *Philosophy and Truth: Selections from Nietzsche’s Notebooks of the Early 1870’s* (1979: 85), the outcome of the labour of scientists is that ‘the great edifice of concepts displays the rigid regularity of a Roman columbarium and exhales in

logic that strength and coolness which is characteristic of mathematics.’

THE ORIGIN OF PROCESS METAPHYSICS AS DEFENCE OF THE HUMANITIES AGAINST PYTHAGOREANISM

While Whitehead’s *Science and the Modern World* was a brilliant achievement in advancing our understanding the Seventeenth Century scientific revolution and its subsequent influence, there are two significant cultural developments that Whitehead either failed to fully acknowledge or to fully appreciate – the development of Renaissance thought, and the contribution of the Romantics to the development of science.

As Stephen Toulmin pointed out in *Cosmopolis: The Hidden Agenda of Modernity* (1994), the Seventeenth Century scientific revolution was a reaction to Renaissance thought rather than Medieval thought. It was a rejection of the Florentine Renaissance and all it stood for, including the humanities. The humanities were concerned to revive ideas from the Roman Republic and Ancient Greece to inspire people to uphold liberty and govern themselves. Central to this was the revival of history, although in its later phases it was also associated with the development of Nature Enthusiasm of Giordano Bruno. The focus on history culminated in the work of Giambattista Vico.

While suppressed in Britain and to a lesser extent, in France, there was another Renaissance in Germany, embracing and advancing beyond the Italian Renaissance. It is here that the conflict between scientific materialism and the humanities came into the open (although it had been appreciated by Vico), with a variety of solutions proposed to reconcile these two very different ways of thinking. The pivotal figure was Kant with his effort to give a central place to consciousness and free agency as the foundations for science, mathematics and ethics, characterizing mathematics and natural science, as Vico had characterized them, as a human constructions. However, Kant’s work inspired a range of other important thinkers (Gare, 2011). Some of these, notably Fichte and Hegel, embraced and developed a form of Idealism in which nature itself was conceived as a construct of the mind, others, such as Herder, Goethe and Schelling, while sympathetic to the Idealists, called for a radical revision of our understanding of nature. The most important problem for these more radical thinkers was to account for consciousness capable of free agency, conceiving

consciousness as a product/producer of history while still being part of nature, rather than simply assuming the reality of consciousness as Kant and the Idealists had done. The most radical solution involved questioning and seeking to replace Newtonian science to uphold a view of nature within which humans as conscious beings could be understood to have emerged as historically developing, and in this context, capable of free agency. Since consciousness is essentially process, and history really focusses on actions and processes, with structures having a derivative status, nature had to be conceived of as essentially process. Friedrich Schelling was the crucial figure in this development (Gare, 2011; Gare, 2013). This, I am arguing, is the tradition of process philosophy or process metaphysics. These ideas were taken up in France, Britain and USA towards the end of the Nineteenth Century, forming the tradition of process metaphysics. This can be viewed as the third Renaissance, the German Renaissance.

My view is that to prevail over the Pythagoreanism of mainstream science, it will be necessary to understand process metaphysics as a tradition developing out of the German Renaissance and to appreciate the history of its development and influences. That is, it will be necessary to take history very seriously, and the role of narratives in history. This includes the history of the challenges to such thinking. As part of this, it is necessary to understand the history of mathematics from the perspective of process metaphysics, of how mathematics and its role in science have been understood. The influence of Whitehead's *Science and the Modern World*, illustrates the importance of this. For those who come to Whitehead's work independently, this work is almost always their first contact with his philosophy and the reason for taking his work, and process metaphysics, seriously. However, partly inspired by this work, further dimensions to this history have been revealed.

I want to take this argument further than the history of science and mathematics, and examine the place of mathematical relations in nature, and then the place of history in nature itself, and finally, the relationship between mathematical and historical relations in nature.

FROM SCHELLING TO WHITEHEAD AND COMPLEXITY THEORY

While there are a number of important philosophers and other theorists, including mathematicians in the tradition of process metaphysics, I believe the

five most important are Schelling, C.S. Peirce, Henri Bergson, Alexander Bogdanov and Whitehead. Schelling naturalized Kant's transcendental argument, developing a form of transcendental realism. He argued that for scientific knowledge to be possible, nature must be conceived in such a way as to make intelligible how beings could have evolved within it able to develop science and comprehend nature and themselves. On this basis, he argued for a radical revision of the categories of metaphysics. In doing so, he advanced Kant's dynamic conception of matter and most importantly, gave a privileged place to Kant's reflections on biology in his *Critique of Judgement*. While accepting Kant's constructivism in epistemology, Schelling radicalized this by characterizing such construction as participating in nature's self-construction, the process through which nature is becoming conscious of itself. Matter was reconceived as activity limited by balances of opposing forces to create forms, which in the case of living beings, are forms that have to be actively maintain themselves in the process of their interaction with their environments. Their environments are then defined as their worlds. Living beings were thus conceived to be to some extent self-causing, or are immanent causes of themselves, living in worlds, consisting of actualities and potentialities, which have meaning for them and to which they respond accordingly, often creatively, creating, pursuing and realizing new possibilities.

In claiming that Schelling's philosophy is the origin of modern process metaphysics, I am arguing that it is this project that underpins the philosophies of Peirce, Bergson, Bogdanov and Whitehead (Gare, 2011). Once this is appreciated, it becomes much easier to show how their insights can be recognized as complementary and integrated, along with more recent work in mathematics, science and process metaphysics. Central to this project, Schelling argued for a philosophical physics to replace Newtonian physics with his conception of nature as dynamic and creative (which indirectly, inspired the work of Michael Faraday and James Clerk Maxwell), and called for the development of new forms of mathematics appropriate to such a dynamic universe. This inspired major work in mathematics. Justus Grassmann was inspired by Schelling to develop a 'fluid geometry', a 'dynamist, morphogenetic mathematics' that would facilitate insight into the emergence and inner synthesis of patterns in nature (Heuser, 2011, 58). Building on this, his son Hermann Grassmann developed extension theory, which he presented as a survey of a general theory of forms, assuming, as he put

it, ‘only the general concepts of equality and difference, conjunction and separation’ (Grassmann, 1995: 33). It was meant as ‘the keystone of the entire structure of mathematics’ (Grassmann, 2000: xiii). He was the inventor of linear and multilinear algebra and the precursor to vector algebra, exterior algebra and Clifford algebra, and included the notion of multidimensional vector spaces, presaging most of the mathematics used in modern physics, and contributing to the development of tensor calculus. Whitehead’s first major published work, *Universal Algebra*, was inspired by Grassmann’s ideas on the philosophy of mathematics. The development of Category Theory, which took place after Bergson, Peirce and Whitehead, was not influenced by Grassmann, but its leading exponent, William Lawvere (1996), argued that Grassmann’s extension theory was a precursor to Category Theory.

Whitehead’s philosophy involved demanding recognition of experience in all its diversity, explaining the development of mathematics as abstraction from this experience, and then developing a cosmology that gave a place to pure possibilities (eternal objects), showing how these possibilities are actualized through processes that involves both a subjective and an objective pole. Mathematics, investigating these possibilities, was then characterized as the science of patterns. The temporality of these patterns was acknowledged by rejecting the notion that the equal sign in $2 \times 3 = 6$ implies that this is a tautology, and interpreting this as meaning that two threes are becoming six. It could be argued on this basis that mathematics as conceived by Whitehead is the study of patterning rather than patterns, understood as realizing possibilities.

At the same time, Whitehead argued that science based on mathematics does not exhaust all that is in nature. He was concerned to do justice to all experience and defended the study of the classics and wrote brilliant works in the history of civilization and science. He obviously took historical narratives very seriously. I believe that the most important component of Whitehead’s metaphysics on the basis of which he could give a place to mathematics while arguing that it could not grasp the whole of reality, giving a place thereby to experience and subjects (or rather, ‘superjects’), and connected to Whitehead’s interest in classical education and history, was acknowledging and analysing immanent causation, the primary causation of causal processes (as Dorothy Emmett argued).

THEORETICAL BIOLOGY

While Whitehead was more influenced by physics than biology, he characterized his philosophy as a philosophy of organism. As with Schelling, overcoming Cartesian and all other dualisms in philosophy involved recognizing the importance of characterizing living beings. His work had a major influence on biologists, perhaps most importantly, the work of C.H. Waddington and his colleagues and students on embryology and epigenesis.

Waddington developed the notion of the morphogenetic field and examined the spatial and temporal relationship between individuated fields, and the causation involved in these relationships. This related his own work to the work of the Gestalt psychologists, and to the genetic epistemology of Piaget. Waddington was particularly influenced by Whitehead's notion of concrescence, concluding from this that major changes in the development of organisms could be the result of immanent causation rather than an external controller (Waddington, 2010). On this basis he developed the notion of necessary paths, or chreods (or 'creods') and homeorhesis – the tendency of a developing field and the forms it is generating to return to its path of development after being displaced from it. He also allowed that there could be major changes of path. He used the metaphor of water flowing down valleys, with the possibility of the flowing water switching to a different valley if it is displaced enough, to model these necessary paths, chreods, homeorhesis, and changes of path. This work inspired the mathematician, René Thom, to collaborate with Waddington and develop catastrophe theory, a development of bifurcation theory through geometry, representing sudden changes through spatial curves.

Waddington's work was further developed by Brian Goodwin, notably, in *The Temporal Organization of Cells* (1963). This work acknowledged the centrality of biochemical feedback loops in living processes, but also examined their oscillations and the relationships between these associated with different frequencies and relaxation times, and the interaction between different feedback loops.

Such work was further advanced by complexity theory facilitated by the use of computers, although complexity theory took different forms with different implications. Goodwin's later work on morphogenesis, Stuart Kauffman's work on autocatalytic sets, and Ilya Prigogine's work on dissipative structures,

exemplified such developments. Mae-Wan Ho, directly influenced by Bergson, Whitehead and David Bohm, integrated such work with Herbert Frölich's biophysics. Integrating thermodynamics with quantum field theory provided the means to examine how quantum coherent electromagnetic fields could play a role in organisms in storing and releasing energy and in communication and coordination within organisms. These ideas were presented by Ho in her book *The Rainbow and the Worm: The Physics of Organisms* (2008).

A different form of complexity theory, hierarchy theory, was and is being developed by Howard Pattee, Timothy Allen and Stan Salthe, in effect rediscovering Schelling's insight that limiting activity could be creative; or as Pattee (1973) argued, constraints could be enabling. Pattee had participated in Waddington's famous conferences on theoretical biology in the late 1960s and early 1970s (Waddington, 1968-72). Allen and Starr (1982), who focussed on ecology, examined the role of different process rates and different scales in hierarchical ordering and Salthe (1993) further developed these ideas, relating his work to that of the biosemioticians.

CATEGORY THEORY

At the same time, a new perspective was being opened up by the development of Category Theory. Category Theory originated with Saunders Mac Lane's efforts to investigate whether and when different branches of mathematics were dealing with the same objects. As such, it was seen as a way of modelling one branch of mathematics by another. It was then elaborated into a general theory of mathematics by William Lawvere. Characterized as an examination of categories in mathematics, it can be seen as justifying Whitehead's claim that mathematics is the science of patterns. One person who took this very seriously was the theoretical biologist and mathematician Robert Rosen. As Rosen characterized Category Theory:

Category Theory comprises the general theory of formal modelling the comparison of different modes of inferential or entailment structures. Moreover, it is a stratified or hierarchical structure without limit. The lowest level, which is familiarly understood by Category Theory, is a comparison of different kinds of entailment in different formalisms. The next level is, roughly, the comparison of comparisons. The next level is the comparison of these, and so on (Rosen, 1991, 54).

As such, Category Theory facilitated the examination of relations to relations.

Rosen (1991; 2000; 2012) was concerned to characterize life itself mathematically. To do so, he began by examining the nature of modelling generally, that is, in both mathematics and science, arguing that modelling is the core of science. He argued that the modelling relation within mathematics, the basis of Category Theory, could be extended to modelling natural processes, claiming that entailments in mathematics can be identified with causal entailments in nature. Focussing on biology, and anticipatory systems in general, he argued (following John von Neumann) that such systems are characterized as having models of themselves in their environments, and mathematical models must include these models in what is modelled. In biology there is usually no readily recognizable external controller, and the system somehow controls itself from the inside. The theory of metabolism-repair (M,R) systems was developed by Rosen as a mathematical extension of the classical setup aimed directly at the formal characterization of such self-referential or “lifelike” systems. In this way, he claimed, final causes and functions could be given a place in mathematical biology. Rosen emphasised that these should be understood as emergent, holistic features of organisms, and that it was a mistake to identify functions with fractionated components, although fractionated components could serve these functions. Modelling life in this way requires the acceptance in mathematics of ‘impredicatives’, that is, self-referencing definitions. Having to accept these, Rosen claimed, makes it impossible to simply model anticipatory systems with computers. This is what distinguishes ‘life itself’ from mechanical processes, and shows why it is wrong to think that when we develop complex enough machines we can identify them as living beings. Living beings, he argued, are not just complex machines.

Rosen’s work was one of the main inspirations for developing a specifically biological mathematics, a project taken up and led by Plamen Simeonov and André Ehresmann under the banner of ‘biomaths’. Concerned to do justice to the reality of life, proponents of biomaths established links with the movement among phenomenologists to ‘naturalize’ phenomenology, in opposition to the idealist turn taken by Husserl in his later work. For the most part, Maurice Merleau-Ponty was invoked by these phenomenologists, someone who himself had turned to natural philosophy towards the end of his life and come to take an interest in

Schelling, Bergson and Whitehead. Links were also made with the biosemioticians.

THE LIMITATIONS OF MATHEMATICAL MODELS

Along with these developments, more and more attention has been paid to the role of models in science, both mathematical and non-mathematical. As noted, Rosen had argued that modelling is the core of science. Max Black had argued this in 1962. However, reflection on modelling has been associated with theorists recognizing and questioning tacit assumptions associated with modelling. Stuart Kauffman, for instance, while radically challenging orthodox biology and science and making major advances to complexity theory in the process, came to the conclusion that his thinking was not radical enough. He began to question the way Newton, Einstein and Bohr had taught us to do science. As he put it in *Investigations* (2000: ix), ‘we are taught to prestate the particles, forces, laws, and initial and boundary conditions, then compute the consequences. In this enterprise, we are able to state ahead of time what the full space of possibilities is, that is, we can finitely prestate the configuration space of possibilities of the system in question.’ Reflecting on this, he came to doubt that we could ever prestate the configuration space of the biosphere. Reflecting on this further, he argued that there are always adjacent possibilities that cannot be prestated.

This is evident with exaptations, developments that take place before they are utilized by organisms for a particular function. For instance, lungs evolved from swim bladders that had served a very different function, but when stressed by lack of oxygen in the water fish were led to gulp air and resolve the problem. Something new came into existence, opening up further new possibilities. With evolution, new adjacent possibilities come into existence as species and environments change, leading to creative co-evolution of species that cannot be modelled mathematically. This does not mean that there is no place for mathematical modelling, but it is also necessary to use stories to account for such creative events. In coming to this radical conclusion he also became interested in both Whitehead and the biosemiotics movement inspired by von Uexküll and C.S. Peirce.

VON UEXKÜLL, PEIRCE AND BIOSEMIOTICS

Von Uexküll argued that an organism can only be understood in relation to its environment where its environment has been defined by it as its surrounding world or *Umwelt*, a world that has meaning for it on the basis of which it responds to what is in its environment. This concurred with the way phenomenologists conceived humans, although, as Heidegger argued, on the foundations of *Umwelten*, humans develop with-worlds, experienced as shared with others from the past, the present and the future, or *Mitwelten*, and then through developing the capacity to reflect on themselves in relation to these worlds, develop a self-world or *Eigenwelt*. Biosemioticians embraced this work but generally, although not always, interpreted these *Umwelten* through Peircian semiotics (Gare, 2002a).

Like Whitehead, Peirce was a mathematician, a major figure in the development of symbolic logic, and steeped in the history of philosophy. He characterized himself to William James as ‘a Schellingian of some stripe’, and like Whitehead, while being influenced by idealism, at the same time defended realism. Peirce defended metaphysics, and argued that the most basic categories are Firstness, Secondness and Thirdness, emphasising the need to appreciate and promote triadicity to overcome the aporias generated by dualisms that had afflicted modern thought. In experience, Firstness is what is immediately given without any relations, Secondness is the reaction to Firstness as its first relation, and Thirdness relates this relation. For Peirce, logic is semiotics, and through his triadicity, he argued that along with deduction and induction, there is also abduction associated with creative conjecturing to guide empirical research and to explain observations. Semiosis was characterized triadically as involving a sign, an object and an interpretant. Peirce’s most general definition of a sign is that which ‘mediates between an object and an interpretant; since it is both determined by the object *relatively to the interpretant*, and determines the interpretant *in reference to the object*, in such wise as to cause the interpretant to be determined by the object through the mediation of the “sign” (1998: 410). An interpretant can then become a sign generating further interpretants. With this triadicity semiosis could become increasingly complex, with instances of semiosis taking place within broader instances of semiosis.

In accordance with Schelling’s philosophy, Peirce’s work situated semiosis as processes within nature. This provided the means for the proponents of

biosemiotics to develop von Uexküll's characterization of organisms and their worlds rigorously and to extend Peirce's ideas on semiotics in doing so. Peirce's point of departure was logic, with signs and interpretants seen in relation to science, as ideas produced in the mind. However, Peirce extended what could be counted as a sign and an interpretant to include not only actions but also changes of form in plants or animals. Biosemioticians embraced and extended Peirce's conjectures in this regard, recognizing symbolic semiosis associated exclusively with humans, animal semiosis in which interpretants are actions, and vegetative semiosis in which interpretants are forms. They gave a place also to endosemiosis, semiosis within organisms, as with the relationship between DNA and proteins. This was associated with the realization that this relationship is associated with codes involved in selecting which proteins would be produced by DNA, and this was followed by recognition of a great diversity of codes within organisms (Barbieri, 2003). Finally, semiosis was extended to the study of the relationship between different organisms and species within ecosystems, with Kalevi Kull arguing the all bonds with ecosystems are semiotic bonds. On this basis, the development of symbiosis and its ubiquity could be explained, consistent with characterizing organisms from eukaryotic cells to more complex life organisms as highly integrated ecosystems. Biosemioticians also embraced the work of Pattee on enabling constraints to characterize semiosis, characterize hierarchical levels of semiosis and the emergence of new levels freedom through what Jesper Hoffmeyer (2008a: 138) characterized as 'semiotic scaffolding'. Hoffmeyer, as a founder and leading member of the biosemiotics movement, was particularly hostile to efforts to incorporate the physicists' notion of information science into biology (Hoffmeyer, 1993: 62-66; Hoffmeyer, 2008a; Gare, 2020), but embraced Gregory Bateson's notion of information as 'a difference that makes a difference', a notion developed out of second order cybernetics whereby cybernetic processes respond reflexively to cybernetic processes (Hoffmeyer, 2008b). This was also the source of Maturana and Varela's notion of autopoiesis; that is, the notion that organisms make their own components. Peirce remained Hoffmeyer's main point of reference.

Not all biosemioticians are happy with the status accorded to Peirce's work by the movement's founders. Some want to make biosemiotics more acceptable to mainstream science, and have sought to align it with information science, or to

make the study of codes the core of biosemiotics. Others have argued for more radical positions, promoting biohermeneutics or post-Peircean pragmatist philosophies to advance biosemiotics. However, my view is that Peircean biosemiotics has the potential to accommodate the insights of the code biologists while at the same time accommodating the insights of the biohermeneuticists and post-Peircean pragmatists, for instance, George Herbert Mead, by providing the means to characterize the role of both mathematics and stories in science, explaining what is being understood through mathematics and stories (Gare, 2022).

SEMIOTICS, MATHEMATICS AND NARRATIVES

Making the claim that Peircean semiotics can grant a place to both mathematics and stories is a bit problematic, because Peirce himself did not characterize mathematics through semiotics, and narratology, the study of narratives which only really developed after Peirce, has divided between proponents of structuralist approaches, claiming to be more 'scientific', and hermeneutic approaches, more aligned with the traditional humanities. However, followers of Peirce have interpreted his own characterization of mathematics along with more recent ideas on mathematics through Peircean semiotics, at the same time, characterizing the deployment of mathematics in science as modelling. And I have argued elsewhere, narratology as developed through hermeneutic phenomenology, most importantly, David Carr and Paul Ricoeur, can be developed further by interpreting their work through Peircean semiotics (Gare, 2001; Gare, 2002b). This approach provides the means to appreciate the insights of structuralist narratologists while upholding the primacy of temporality emphasised by the hermeneutic phenomenologists.

Peirce characterized mathematics as necessary reasoning, following his father, and then as diagrammatic reasoning. He claimed and showed how mathematics could be advanced through the study of diagrams, in doing so, providing insight into reality. However, he did not characterize this as semiosis. In a relatively recent work, *Mathematics as Modelling System: A Semiotic Approach* (2014), Marcel Danesi and Mariana Bockarova have defended Peirce's characterization of mathematics by characterizing it thought through Peircean semiotic theory, at the same time providing a history of mathematics, including its notations, and the way it has been understood up to the present. Interpreting Peirce's work as

semiotics involved applying the Peircian theory of modelling (Modelling System Theory), to the study of mathematical modelling, something that had not been done before. These ideas were further advanced by using Conceptual Metaphor Theory as developed by George Lakoff and Rafael Núñez in *Where Does Mathematics Come From: How the Embodied Mind Brings Mathematics Into Being* (2000). Here it is argued that all concepts emerge through the articulation of metaphors, with the most basic metaphors being schema originating in our embodied engagement with the world. In support of this claim, these authors referred to Saunders Mac Lane's observation that all branches in mathematics originated in new practices. As such, mathematics is both invention and discovery, involving imagination, but by originating in practical experience, doing so in a way that reveals facets of the world. As Lakoff and Nunez put it (2000: 135): 'Mathematical models allow us to represent the world in various ways. At the same time, they serendipitously unravel patterns within nature itself.' This, they claim, is what Peirce was characterizing as abduction. It is consistent with Rosen's characterization of modelling and what is involved in applying models to elucidate what is being investigated.

This raises the question of the relation between different metaphors and different models, and it is here that narratives are essential. Recognition of the role of metaphors in science in reaction to logical positivism led to relativism, since there appeared to be no absolute reference points for judging one scientific theory superior to another, or whether or not they could be reconciled. Alasdair MacIntyre (1973) argued that major advances in science can be judged as such through the historical narratives they make possible of past science, accounting for its achievements but also revealing why it failed, and why its failures could not be solved without a radical break with the assumptions of this earlier science. This can involve changing what science is understood to be. Such narratives also define present problems and orient scientists in their further research. The same claim can be made for mathematics or any other abstract area of inquiry. MacIntyre (2007: 216) argued that narratives orient not only scientists but everyone in their everyday lives. To know what to do and how to live, we have to understand what stories we are participating in, and it is through participating in these stories that we learn how to question and reformulate these stories.

This claim was strongly defended by the hermeneutic phenomenologist,

David Carr in *Time, Narrative, and History* (1991). Central to Carr's conception of narrative is its relation to action. All human actions, he argued, involve narratives whereby completed states of affairs are envisaged on the basis of interpretations of the present and anticipations of the future, at least in vague form, and embodied individuals are oriented in their current situations by these narratives to bring about these envisaged state of affairs. They are above all orientations for action. This is clearly true of joint actions where shared narratives facilitate coordination of vast numbers of people over generations, but it is also true of the actions of individuals. Actions involve component actions, often more complex than the overarching actions, and this is taken for granted in narratives. Historical narratives are about actions, and therefore include the actors' narratives that constitute their actions.

All this can be reformulated through Peircian semiotics in which actions are understood as interpretants of signs produced by both previous and current interpretants, including non-human interpretants. However, it should be clear that interpreting narratives in this way requires acknowledgement that semiosis does not occur atomistically. In defining situations and formulating projects, each instance of semiosis is in the context of a complex of other instances, commonly in hierarchical order with some instances of semiosis being components of broader semiotic acts. This complexity becomes clear when characterizing these complexes of semiosis as narratives. As lived narratives unfold in the context of broader narratives and are composed of shorter, more specific narratives, so instances of semiosis will take place in a context of a broader instances of semiosis and be composed of more specific semiosis.

Understood through Peircian semiotics extended in this way, narratives are more fundamental than and the condition for mathematical research and scientific research utilizing mathematical models. The successful use of mathematical models always involves the assumption of boundary conditions, either naturally produced or artificially produced in the case of experimental situations or machines designed to behave predictably, and these boundary conditions cannot be described through the mathematical models being deployed. Mathematics also presupposes a schematic understanding of the history of mathematics, and the same is true scientific research. It is not only through such history that it is possible to judge where to use some branch of

mathematics, but also to judge understand the context within which mathematically defined relationships can be found. This includes the boundary conditions required for such relationships to be possible. The economist Joseph Schumpeter appreciated this when he argued that economic decisions should be informed by economic history, statistics, and mathematical models, and the most important of these is economic history. Without the context provided by such history, mathematical models are likely to be misleading. Lastly, from the perspective of process philosophy, narratives are more fundamental because they focus on processes, while mathematical models are timeless abstractions and abstract away from process. They can identify and provide insight into structures and recurring patterns, but cannot fully capture the process of emergence of these structures and patterns. That is, unlike narratives, they are unable to fully grasp immanent, creative causation which they have to presuppose, and it is for this reason that they are also blind to subjective experience.

Biosemioticians have revealed the ubiquity of semiosis in living beings. While the term 'model' might be seen as problematic, they have justified Robert Rosen's claim that living beings must have models of themselves. As a mathematician, Rosen was concerned with models of causal entailments that could be modelled mathematically. This is appropriate when examining stable structures and patterns, but it clearly is inadequate when it comes to the situations described by Kauffman (2000), and is therefore unable to account for creative adaptations associated with new relations developing between living processes, or the resulting co-evolution of organisms and species, which is an essential part of evolution. In the past, this has been dealt with by claiming that random mutations and selection of those which prove to have utility for survival account for such evolution. Elsasser, a physicist, did the calculations and found the universe is not old enough for such a mechanism to work. It could no more account for the evolution that has taken place than account for the advance of through scientists producing random ideas which can then in some way selected. Abduction is required for to develop such ideas, involving a kind of intelligence that is neither deduction nor induction. And it appears that something like this is required for organisms to respond to new situations generated by new situations, crises, or changes generated by such co-evolution. If this is the case, might not the 'model' an organism have of itself be something like a story or narrative? And if organisms

are just highly integrated ecosystems, might not ecosystems themselves sustain a story of themselves that guides to some extent how they develop?

INTEGRATING WHITEHEADIAN AND PEIRCIAN THEORETICAL BIOLOGY: SEMIOSIS AND BIOFIELDS

It is in attempting to answer these questions that the limitations of biosemiotics becomes evident. It becomes evident in considering the relationship between DNA and signs. Biosemioticians generally are dissatisfied with the view that DNA simply encodes information as the basis of the relationship between genotypes and phenotypes. Even granting a place to mediating codes, that is, quasi-conventional mechanisms for utilizing DNA to produce proteins, does not explain this relationship. For instance, it is not adequate to account for how DNA is utilized in the epigenesis of multicelled organisms, since the same piece of DNA can utilized to produce different proteins. And as the human genome project revealed, there is simply not enough DNA to account for the complexity of the adult organism. It is necessary to heed Rosen's argument in showing that organisms must have models of themselves that these models should not be identified with fractionated components of the organisms. The model has to be seen as a function, and a function is a feature of the whole organism, although fractionated components can be utilized as mechanisms serving these functions. Mechanisms imply a telos and can only be identified as such through a telos, and the telos is a feature of the whole organism.

To deal with this issue, it is necessary to integrate biosemiotics with the tradition of theoretical biology inspired by Waddington under the influence of Whitehead. Through this integration it can also be seen how the different strands of process metaphysics, most importantly, those inspired by Whitehead and those inspired by Peirce, can be integrated as part of the broader tradition of process metaphysics going back to Schelling and including insights of Bergson and other process metaphysicians. Waddington developed the notion of biological field, specifically, the morphogenetic field, or rather, morphogenetic fields, since the process of development involves the individuation, emergence and development of a multiplicity of sub-fields and sub-sub-fields etc. interacting with each other, but developing to some extent according to their own immanent dynamics.

What Waddington's work on embryology revealed very clearly was the reality of emergence. It is on this basis that I have proposed the notion of ecopoiesis in

place of autopoiesis to characterize what is involved in such emergence. The notion of ‘autopoiesis’ does not acknowledge the emergent dynamics of what emerges in epigenesis. Ecopoiesis implies that the developing embryo creates the conditions for the emergence of a whole sequence of self-organizing, interacting fields characterized by different temporal features. That is, organisms create new ‘homes’ or niches where new fields can emerge, including fields within fields. What counts as signs for taking various paths in this process, including signs in the environment of the field, can only be understood in relation to these fields as self-organizing wholes. DNA is important, but each field utilizes the DNA in its cells in different ways, although this can be influenced by the bio-field of the organism as a functioning whole. This broader field, the field of the organism as a whole, can influence all the subfields in subtle ways, as when the horned grasshopper develops as a locust rather than an ordinary grasshopper. It is only in relation to these partially autonomous fields that canalization of development can be understood, including the switching between different possible paths of development. Semiosis needs to be understood in the context of these developing fields, as does anything characterized as ‘information’, which should always be understood as Bateson characterized it, as differences that make a difference.

The contributions by mathematical biologists to comprehending this whole process have been important, but they have only illuminated different facets of what is involved. Thom’s catastrophe theory was illuminating, but it did not capture the whole development of organisms. Similarly, the two phases of Goodwin’s work, Kauffman’s work on autocatalytic sets, Prigogine’s work on dissipative structures and the role of these in influencing how cells relate to each other (as when the fluctuations of acrasin guide individual slime mould cells to aggregate into a multi-celled organism), have all been illuminating, but there is no mathematical model from which each of these can be deduced to model everything that is involved. It has proved impossible to develop a mathematical model that captures the whole process of morphogenesis.

And this is what one would expect of abstract models, which to be illuminating have to abstract away from the complexity of what they are investigating. As David Bohm in *Science, Order, and Creativity* (2000: 8), following Alfred Korzybski, argued, ‘mathematics is a limited linguistic scheme, which makes possible great precision and coherence – but at the expense of such

extreme abstraction that its applicability has, in certain ways, to be bounded.' The causal entailments revealed in such mathematical modelling are real, but are in the context of and bounded by processes that can respond globally to new, unanticipated situations and possibilities, which, altering these boundary conditions, can alter what is entailed. This relationship, along with many other relationships made intelligible through process-relational thinking that gives a place to the reality of possibilities and relations between and to them, has been examined in great depth by Tim Eastman in *Untying the Gordian Knot: Process, Reality, and Context* (2020, *passim*, esp. ch.5). The whole process can be better understood as a developing story in which the whole organism and its developing component fields are responding to a diversity of signs, which can be signs left by the progenitors of the organism, but defined as such by the interaction of these fields with their components and contexts. This can be seen as the organism's developing a model of itself influenced by what has happened in the past to its progenitors, which constrains its development, while responding creatively to changing environmental conditions, failures in normal development, or radically new situations (Gare, 2022).

If this is the case with an organism, and an organism is just a highly integrated ecosystem, it is possible that ecosystems also not only develop in ways that can be narrated as stories, but involve proto-narratives as models of themselves, influencing the way they and their component organisms develop and interact with each other. If the biohermeneuticists Anton Markoš and Jana Švorcova (2021) are right in the claims they make in *Epigenetic Processes and the Evolution of Life* (2019), ecosystems could respond to situations by upholding Norms, remembering basic rules, based on what has happened in the past, through the influence of shared DNA of protokaryotic cells. Such thinking can now find support in the work of theoretical biologists arguing for a place for purpose in evolution (Corning et.al. 2023).

agare@swin.edu.au

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