Relativistic Ontologies, Self-Organization, Autopoiesis, and Artificial Life: A Progression in the Science of the Autonomous

Part I — The Philosophical Foundations

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Abstract

Autopoiesis is a very powerful way of looking at and dealing with autonomous systems. It also has some major implications for the philosophy of science. Unfortunately, it is not clear in what philosophical context one should go about using autopoiesis. In this paper, we look at these issues, touching upon the inadequacies of conventional (positivistic) ontologies and philosophies of science, and we briefly describe an alternative relativistic ontology. We argue that self-organization is a necessary condition for autonomous systems and we highlight the difficulties that this raises for conventional representational approaches to autonomous systems. We discuss a methodology for discourse in relativistic ontology (*Systematics*) and, based on this, we argue in favour of a spectrum of autonomy. In a sister paper, we then try to show how autopoiesis can be interpreted as a particular instance of autonomy in this spectrum. We proceed to describe the progress which has been made towards the development of a computational simulation of autopoietic organization, beginning with a formulation in terms of the calculus of indications (incorporating Varela's extensions to include autonomous forms), and incorporating the *Systematic* formulation.

1 Prologue

This paper takes as its subject matter issues which have been of interest to man for more than two millenia. It addresses perception, cognition, intelligence,

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ontology, the philosophy of science, and the very essence of life itself. All of these topics are bound up in one issue: autonomy. What is it to be autonomous? How do entities come to be autonomous? Can we, as technological masters, construct truly autonomous systems? If so, how? And if not, then what can we learn about ourselves — archetypal instances of autonomous systems — in the process? These are the questions which we address in this paper.

The position on autonomous systems to which the paper leads is not a conventional one. It contrasts the current, and now classical, computational approach which is perhaps best exemplified by the discipline of computer vision. According to conventional wisdom in computer vision, information about the world is presented, in implicit form, to our sense organs as incident light. A sequence of processes abstract the useful information about the world, beginning with the scene image, producing successively richer and more parsimonious representations, and culminating in, at the very least, an unambiguous representation of the local environment. Modules of geometric and spatial reasoning facilitate recognition and manipulation of these models and, optimistically, the vision system can then formulate the appropriate actions required to intelligently react to the stimuli. This information processing paradigm is unashamedly positivistic in its outlook, being based entirely on the premise that there is, indeed, an absolute knowable world which has only to be apprehended by our senses (or the senses of our robotic system).

In this paper, we will take a different approach. Not because we wish to challenge or supplant the useful role of conventional, representational, approaches — for they have an important part to play in, e.g., engineering control systems — but because we wish to challenge the ability of such approaches to deal with the issues of true autonomy, with all its attendent concerns of perception, cognition, intelligence, adaptivity, and understanding. Following the work of others,[1] perception in particular, and cognition in general, are explained not as processes of information acquisition, abstraction, or representation, but in terms of the systemic activities of closed self-referential self-specifying autonomous entities. Such cognitive systems are necessarily open systems, from the point of view of the components that comprise the system, but they are organisationally closed: they exhibit a well-defined complete self-organization which is independent of the particular make-up of the structure supporting that organization. From this perspective, the modelling of perception is an ill-posed problem; rather it is by studying and modelling autonomous systems that an understanding of perception emerges.

If the stance on perception and cognition is unusual, the position on the nature of reality which underpins the explantion of perception and cognition is even more unconventional. The position we adopt in this book is that there is indeed a 'real' universe out there, but it is not the world as it is apprehended by

[1]The people who have had a major influence on the work described in this book include J.G. Bennett, H. Maturana, and G. Spencer-Brown, and F. Varela.

us. The world we experience arises from our participation in it; to coin a phrase: 'We shape the world by the way we are'. Our perceptions are our response in ensuring that we remain intact – alive – in that world. Perception, in general, is the response of an autonomous entity in interaction with the universe such that the entity remains viable in its interaction. Pursuing the metaphor: 'We shape the world by the way we are to ensure that we remain as we are'. The nature of reality, then, is fundamentally constuctivist, and subjectivity and personal experience are inextricably linked with objective existence.

2 Autonomy and the Limitations of Scientific Ontology

2.1 Autonomy

The word autonomy conjures up images of self-reliance and independence, self-sufficiency, and isolation or separateness. The difficulty is that such autonomy never exists. There is no such thing as a wholly-closed independent self-sufficient isolated autonomous entity. Autonomy certainly involves these issues, but there is more to it than that. Systems, whether autonomous or not, are defined in a context, in a universe of discourse; a domain of instantiation, if you will. That is, a system exists as part of something. Autonomous systems too exist, not in complete isolation (for then we could never have knowledge of them), but in some reference domain. On the one hand, when we speak of an autonomous system, we speak of a system which has an identity and which is capable of maintaining that identity. But, on the other hand, we must ask of what is it autonomous. We must look at the relationship between the autonomous entity and its universe. At first sight, this may appear to be contradictory: autonomous systems are independent and self-determining while the presence of a relationship with their local universe implies the opposite. The resolution of this apparent paradox is the key to discussing autonomous systems. You cannot discuss the one without making some statement on the other. It is the mutual relevance of the two and the mutual specification of the two by which autonomous systems arise. This contrasts strongly with non-autonomous systems where the system is an aspect of — a direct component of — its environment, controlled by it and used by it.

The study of autonomous systems, then, necessitates that we must look at, not just the requirements, the mechanisms, the formalisms for discussing autonomy *per se*, but also the nature of the universe which plays such a pivotal rôle in the definition of the autonomous system itself. If the thesis which will be put forward and argued in this paper is to have any importance at all, it must then make reference to the most fundamental of all contexts: the nature of reality. For, as soon as you start to plumb the depths of the meaning of autonomy, you are quickly led to try to uncover what is the essential ground on which we are going to build our systems. To do this, we cannot avoid then

asking such fundamental questions as concerns the existence of entities and the nature of existence. While we can neglect such questions to a large extent with non-autonomous systems, as we can accept as real whatever components are being controlled and doing the controlling, and concentrate then on the behaviour of the systems, we cannot do this with autonomous systems because we cannot ignore the mutual relationship between the autonomous system and the universe of which it autonomous. An understanding of the relationship requires an understanding of the nature of the components which comprise the total environment.

2.2 Foundations of scientific ontology

The concept of reality, as it is dealt with in philosophy, is an old and hoary problem and there is a spectrum of philosophical positions which are commonly adopted. In a simple sense,[2] this spectrum is bounded at one end by *realism* and at the other end by *idealism*.

Realism is a doctrine which holds that the objects of our perceptions are what are real and that reality is what is directly perceived; it is through our perceptions that we apprehend the actual real external world. The tradition of modern realism has an impressive pedigree, beginning perhaps with Ockham (1285–1349) and continuing through Gallileo (1564–1642), Hobbes (1588–1679), Locke (1632–1704), Hume (1711–1777), Moore (1873–1958), and Russell (1872–1970). Gallileo, along with, e.g., Copernicus, Descartes, and Kepler, heralded the beginning of the scientific age which placed all empirical measurement and quantification along with rigourous mathematical (or logical) reasoning as the cornerstones for the construction of knowledge. This empiricist ethos was strengthed by John Locke, a quintessential realist, who held that reality is external and is perceived indirectly by the senses. Perception is conceived as a causal process whereby physical stimuli act on the sensory apparatus to produce ideas (or representations, in the modern parlance). Much of today's common understanding of ontology is a legacy of this Lockean frame of mind. It is interesting too that in Locke's philosophy we do not have *direct* apprehension of reality — only indirect ideas or representations of it and in this way he anticipated the conception of noumenology and phenomenology of later philosophers. In all realistic viewpoints, there is the underpinning assumption that reality exists — it is there — and, whether rationally by reason or empirically by sense, we apprehend it and thence come to understand its form and structure.

Idealism, at the other end of the spectrum, is a doctrine which posits that reality is ultimately dependent on the mind and has no existence outside of it. In one sense, this doctrine denies absolutes since, without a single mind, there will be many subjective realities. Invoking God, as Berkelely did, gets us over this

[2]Our endeavour here is less concerned with being faithful to each nuance of every philosophical position and more with caricaturing the situation to highlight the essence of these philosophical positions.

difficulty but at the expense of introducing a new, absolutely inaccessible, term. If Locke was the quintessential realist, then Berkeley was the quintessential idealist. Berkeley (1685–1753) developed, and subscribed to, the philosophy that nothing exists save that which is perceived by a mind. This is neatly summarized by his famous aphorism '*esse est percipi*' — to be is to be perceived — and, thus, the reality and existence of an entity is premissed upon that entity being perceived (or perceiving). This is not to say that the entity 'vanishes' if it is no longer perceived nor that it is in some sense ethereal: the entity 'really' exists but Berkeley's position is that our idea about it are based on our perceptions of it. In this sense, Berekeley is also proposing an empirical point of view — that our knowledge of the world is gained exclusively from our senses. On the other hand, Berkeley denied the existence of matter: what exists is that which is perceived, and it exists because it is perceived. Reality pervades all perception but corporeal matter has no place in this scheme. This denial of the reality of matter is significant for it clearly distinguishes Berkeley's empirical idealist notions of perception from the realist, empirical, notion that perception is an abstraction or apprehension of the (material) world *via* a causal process of sensing.

Immanuel Kant (1724-1804) was also an idealist, but his views differed significantly from those of Berkeley. Kant differentiated between *noumena*, the domain of 'things in themselves' and *phenomena*, or the 'appearances' of things as they are presented to us by our senses. Kant argued that noumena are not accessible to us, and cannot be known directly, whereas the phenomena — the contact we have with these things via our senses and perceptions — are the basis for knowledge. Kant refers to noumena as 'trancendental objects' and his philosophy is sometimes referred to as 'trancendental idealism'. Thus, Kant admits the 'reality' of a domain of objects, the unknowable noumenological domain. On the other hand, he maintains that the objects of our experience are the only knowable objects and it is the mind that shapes and forms these sense data and, hence, for us, these objects are the only objects that really exist and they exist *because* of us and our minds. Reality, then, exists as an unknowable, non-sensible, noumenal domain which gives rise to the phenomenal domain of our senses. Viewed in this light, Kant can also be seen as supporting a form of realism. This is significant as it is a position which has begun to be echoed in the work of current philosophers. In any event, the idealist tradition did not stop with Kant and has been added to by, e.g., Schopenhauer (1788–1860), Nietzsche (1844-1900), and Hegel (1770–1831).

There are many variations on these two themes of idealism and realism, perhaps the most famous of which is *dualism* which holds that reality comprises two distinct 'substances': one physical and one mental. To clear up any confusion we might remark here that realism and idealism are both monistic philosophies, i.e. reality is comprised of one 'stuff'. Dualism, then, stands between and accepts something of both of these two extreme types of monism. Dualism was first propounded as a philosophical system by Rene Descartes (1591–1650) who

argued for the existence of *two* domains of reality: one corporeal and one non-corporeal. Both mutually-exclusive domains exist concurrently. It is this mutual exclusivity which has caused dualism most of its problems for, if they are truly mutually exclusive, how can they interact? This difficulty has been transposed into modern philosophical debate as the so-called 'mind-body' problem. Here, one is faced with the problems posed by the premiss that there are two domains: one, the body, and the other, the mind. The body is the corporeal reality while the mind is the metaphor, or mechanism, depending on your standpoint, for non-corporeal reality. Again, we are presented with the obvious paradox that if these are mutually exclusive entities, then how do they 'communicate' as they most manifestly do?

Here, perhaps, it is pertinent to make a comment on the *popular* conception of dualism *vis a vis* the philosophical system of Descartes. In recent times, dualism has become a metaphor for representationalism: a world view which posits a polar distinction between object and subject — between perceived and perceiver — and, in a weak sense, between the real and the abstraction of the real (i.e. the representation). This is particularly true in modern Artificial Intelligence research where, utilizing information technology, models and simulations of so-called intelligent systems are constructed. Information technology systems routinely base all of their reasoning upon representations: data structures or internal abstractions of the information which is passed to it and extracted from it. We would like to argue here that this is a very bastardized view of dualism. Where, for example, *is* a data-structure in a computer? Where does it exist? It has *no* existence save that of the distribution of charge — electrons — in the electronic substrate that constitutes computer memories. In this case, representationalism, or bastardized dualism, has far more in common with Lockean realism than it does with Cartesian dualism.

It might also be argued that true dualism, then, has a certain commonality (or parallel) with the noumenological and phenomenological positions of, e.g., Kant's philosophy, the corporeal corresponding to the phenomenal and the non-corporeal corresponding to the noumenal. But this is again a bastardized interpretation of these domains for it presupposes that noumena are, i.e. they exist, in 3-D space (or a 4-D space-time continuum) and, furthermore, that they are isomorphic with the phenomenological domain. This is quite contrary to the actual developments of Kant: noumena and phenomena are *not* dualistic and are not mutually exclusive.

In the above, we have attempted the impossible: to summarize five hundred years of philosophical thought in a few paragraphs. Nonetheless, from this cursory look at the history of western philosophy, it is clear that the philosophical positions on existence and being have been dominated by realism (including the bastardized version of dualism). Additionally, the philosophies that have been most closely aligned with the scientific method have also been those of realism. In a sense, neither of these observations are surprising since realism is the more immediately common-sense view: things exist — we perceive them. It

is this common-sense intuition that underpins almost all of our common scientific enquiry, an enquiry which is almost entirely empirical in its investigation and rationalist, or mathematical, in its methodologies. It has given rise to an unquestioning mode of thought which has been copper-fastened this century by the logical positivists, e.g. Moritz Schlick (1882–1936) and Rudolf Carnap (1891-1970), who hold that reality is exactly that which yields to empirical investigation and anything that is not verifiable by empirical investigation is meaningless. We use the term 'scientific ontology' to symbolize this perspective on being and existence which has emerged amongst the scientific community as the popular and pervasive 'world view'. We are not arguing that this is necessarily the world-view held by contemporary philosophers (e.g. see [8]) or scientists (e.g. see [3]); rather, we are arguing that it is the pervasive paradigm of existence. Our contention is that this naïve position is very damaging for, just as natural philosophy evolved into modern science, modern science, in the guise of research in artificial intelligence and artificial life, is now carrying the torch of modern philosophy; perhaps not the philosophy of the professional philosopher but of the experimental philosopher. And, given that artificial intelligence and artificial life research has a far broader audience than does professional philosophy, any philosophical naïvity on the part of such scientists can only retard the advances we seek to make in developing, and disseminating, a vibrant and deep-seated understanding of what are fundamentally important philosophical issues. The development of a science of autonomy, I hold, is an important aspect of this endeavour.

2.3 Relativistic onotology: Realism and Idealism combined

There has, however, been a development in philosophical thinking, which begins with Kant's distinction between noumena and phenomena, and has evolved into a type of reconciliation of the idealist and the realist positions. It was developed by Edmund Husserl (1859–1938), who held that reality is personally and fundamentally phenomenological but is set against an objective spatio-temporal world. But it was best espoused by Martin Heidegger (1889–1976). Heidegger denied the dichotomy between the world and 'us' and saw existence or 'being in the world' as our activity in a constitutive domain. Reality does not exist 'outside us'; we are beings in a world, not disjoint from it. It is this commonly-accepted disjointedness, this subject-object duality or polarity, which underpins conventional rationalist and empiricist understanding of science and which is the cause of so many of our philosophical problems. It is significant too that our language, with its subject-object structure, promulgates this mode of thought and understanding. What is real is experience and, in particular, our experience of being. What we perceive depends on what it is we are. This thesis is central to our development of a sound philosophical basis for a scientific investigation of the possibility of replicating (or synthesizing) artificial autonomous systems.

The pervasive 'popular' positivistic paradigm of reality — scientific ontology — necessarily involves an absolutely reductionist axiom of binary existence: Either it exists or it doesn't; 'it' being the most irreducible entity (that we can currently conceive). The problem with this extreme reductionism is that, while it is all very well to reduce the macroscopic world to microscopic elements, if we are interested in composition, it renders impossible the endeavour to construct macroscopic entities of a higher order of organization from the microscopic: something is lost in the reduction. What is this something? There are those who would argue that this something was never there in the first place and that it was never lost. It is difficult to refute this claim if we accept that the domain of the reduced is all that there is. But at the same time, those who adopt such a position cannot account for the presence of emergent properties, the most pertinent example of which is life itself, nor can they adequately explain how these emergent properties arise.[3] The problem, again, lies firmly in the lap of our axiomatic acceptance of this reductionist ground — the paradox disappears once the axioms are questioned. If we allow a more relativistic position, that there are levels of existence, levels of being, then we have a way out of the paradox. What do we mean exactly by the terms 'levels of existence' and 'levels of being'? As we noted above, we commonly associate a binary value with existence — either something exists or it doesn't — and we do the same with the term 'being'; it is or it isn't. The is no middle ground. I wish to assert that the notion of a relativity of existence, a spectrum of existence, is useful; that is, there are degrees of reality. Some 'things' are more real than others. With this notion, the word 'being' now takes on a new richness, for we can speak of things with more, or less, being-in-the-world (*c.f.* Heidegger). That is, they and their context in the world, are more, or less, real. It follows that our perceptions, conceptions, and experience of reality are contingent upon the level of one's being in that world, i.e. the relative coherence or organization that we, as autonomous entities, have achieved on the ontological scale.

It is significant that this relativistic position re-asserts the primacy of the individual and his or her experience in the rôle of things, for the idealist position is that the observer is the prime entity upon which the reality of his or her world is contingent. But we have to be careful that this is not a position which is adopted for any anthropic reasons. It does not say, or attempt to say, that the observer, the perceiver, is in any way the centre of the universe, that the universe is anthropocentric. Indeed, the place of the individual is far removed from that; while they may have a part to play in the cosmological scheme of things, the entire cosmology does not hinge on the individual.

The realistic position contributes to this cosmological aspect of reality. There

[3]Note, however, that there have been some very plausible attempts to explain life as spontaneously-arising instances of self-organizing dissipative systems, e.g., see the work of Babloyantz. We would not disagree with this stance, and the importance of the concept of self-organization will arise again later, but we would take exception with the position that it is the only issue involved.

is unquestionably a universe which exists independently of us as observers; the question, of course, is whether or not this is the universe we perceive. The traditional realistic position is that it is and that the rôle of the perceptual apparatus is to generate faithful representations of this real world. By perception, we apprehend the absolute reality.

The position which is supported by a relativistic ontology is subtly, but significantly, different from this. The position is as follows. We play a rôle in defining the universe, but only insofar as it affects us as individuals (the idealist aspect), that is, insofar as it affects our experience of reality; the reality that we perceive does exist (the realist aspect) but our perception and conception of it is conditioned by our experience. Thus, reality is for us a personal experience, though it derives from a common source and this reality is our experience and is contingent upon the current ontological status of us a entities in that universe. In this sense, we are constructivists: as perceivers, our perceptions of the world are a function of what we are. And what we are is contingent upon our level of existence or being, on the ontological scale.

So we have three important conclusions. First, we are part of reality. Second, reality is for us our experience. Third, our experience is contingent upon our ontological status.

If there is a relativity in ontology, a spectrum of being and existence, then it follows that there is the *potential* for entities to have one or other levels of existence or being. That is, every entity has the potential to *be* at a given level. The potential which is currently manifested, we will refer to as the 'actualized' state. Now organisation, the concept for which we heretofore had no ground, is at once well-founded: it is not a *thing*; it is an indicator on the scale of potential actualization: a position within a spectrum. And life, then, exists at (and after) a critical point on this spectrum, i.e., at a critical point of organization. The same holds true of autonomous systems.

2.4 The conclusion

We can now return to the central theme of this paper: the design and implementation of autonomous systems. To reiterate our position, autonomous systems and life-forms are manifested at a critical level of being, of existence. Consequently, these concern the noumenal level of the universe (i.e. it requires not and is not contingent upon the phenomenology associated with humans). Organisation is an indicator on the scale of potential actualization.

Can we create the conditions for artificial life? In principle, yes; by facilitating the spontaneous *self*-organisation of the potential elements of reality. Since anything that we do, as humans, is done in our phenomenological domain, we cannot alter directly the noumena to bring about the required level of existence or being of an entity such that it is alive. All we can do is arrange the conditions whereby the existence of life arises for itself, elevating its own being, existence, and, since we identified organization as a point on a scale of being/existence,

hence self-organizing. But such 'arrangement of conditions' requires that we reach beyond the phenomenology which is our experience and deal directly with the noumenology which is, to all intents and purposes, completely impracticable.

And so, are all our everyday scientific endeavours doomed to failure? Absolutely not. Nothing in the foregoing argument precludes the *simulation* of life, by effecting the same principled organisation with the stuff of our phenomenology. And it should be clear by now that this is not the same thing as creating life. Nonetheless, we can work with the organizational principles which underpin the actualization. In this way, we can indeed develop autonomous systems which display life-like qualities but which are not alive. What we are saying is this: *autonomous systems can arise though self-organization in a noumenological domain or in our phenomenological domain. In the former case, they are life-forms whereas in the latter, they are effective simulations of autonomous systems.*

3 Constructivism and The Implications for Autonomous Systems

3.1 Perception and Cognition

To recap before proceeding, we argued in the previous section that the position at which an entity is placed in the ontological spectrum is equivalent to its organizational coherence. At a critical point on this spectrum, the entity achieves a level of organization, of existence, and of being. The experience of this entity becomes non-trivial and it, consequently, specifies its reality. Significantly, this specification is such that this entity's experience, its reality, facilitates its existence and its being. At this critical point, there is a spontaneous emergence of self-specifying, self-determining, self-reliant systems: autonomous systems.

Autonomous systems derive their autonomy from their intrinsic self-organization. This self-organization implies a dynamic relationship between the autonomous system and the universe of which it is a part. In this dynamic relationship, the components which constitute the system are continually organized and reorganized, new components entering the sytem, and components leaving. What remains constant is the identity of the system, in that an entity with a given self-organization endures. In a strong sense, the autonomous system distinguishes itself from the environment and maintains that distinction. Specifically, it maintains that distinction in the face of (despite) the independently fluid and changing nature of the universe of which it is a part and in self-distinction from the local universe. This formulation of autonomy owes a great deal to the work of Maturana and Varela (see, e.g., [9, 13]). Maturana and Varela introduce the concept of autopoiesis — self-producing systems — and we will discuss autopoiesis in detail later in the paper. We are basically asserting the same thing here but we have come at it from a slightly different perspective. The

framework is somewhat broader than that conceived by Maturana and Varela but it supports their thesis.

We would like now to interpret the terms perception and cognition in the context of what we have been discussing. Given that autonomous systems exhibit a critical level of (self-)organization, and given that this implies a dynamic relationship between the environment (or universe) and a dynamic relationship between the components which constitute the system, then we might search for a phrase which describes this autonomous activity. We could, perhaps, use the phrase dynamic self-organization and self-specification and self-distinction. But this would be a little clumsy. We more commonly use the terms perception and cognition to refer to what an autonomous systems does and we would like to argue that the concepts of perception and cognition are identical to the self-organizing, self-determining, self-specifying systemic activity which is a part of and is required of an autonomous system as it distinguishes itself from the environment. Perception is the term which we could use to emphasise the aspects which pertain to accommodating the perturbations on the system by the environment while cognition is a term which we could use to emphasise the aspects which are internal to the system and which could be interpreted as the 'making sense of' the world (c.f. creating representations). These two words then reflect the realist and the idealist aspects of the relativistic ontology on which the existence of the system is premissed. Perception corresponds to the realist part: the apprehension of the external 'reality'; cognition to the idealist part: the construction of sense of the universe. The important point to appreciate is that they are all just different perspectives on a single thing: the critical level of existence and being which an autonomous system has achieved. The study of autonomous systems is, in effect, the study of spontaneously self-organizing, self-determining, systems which exhibit a structural plasticity but an organizational constancy. By this means, autonomous systems manage to preserve a fixed – enduring – identity, despite the fluid and dynamic nature of the universe of which they are a part. The organizational principles which facilitate this dynamical relationship constitute the subject matter of autonomous systems.

3.2 And Action

We have interpreted the words perception and cognition as systemic activities which arise because of the autonomous relationship between the system and its environment. The connotation of these words is one of information flow from the environment to the system (or certainly one of learning about the environment). Perception is a word which connotes abstraction. There is another interpretation which can be placed on this self-same autonomous activity which arises as the autonomous entity maintains its identity as it distinguishes itself from its enironment. This interpretation is the view of the systemic activity as the *action* of the system: a system acting upon an environment and in an environment. Because the autonomous systemic activity is the same in both

cases, it is clear that perception and action are the dual of one another: two perspectives on the one reality. In the case of perception, the systemic activity is interpreted as an 'abstraction' of a perturbation of the system by the environment while in the case of action, the systemic activity is interpreted as a response to the same perturbation.

3.3 The Contrast with Conventional Perspectives

In this paper, we are espousing a constructivist approach to autonomous systems in the sense that autonomy arises when an entity achieves a level of existence or (self-) organization and that in this self-organization the entity distinguishes itself from its environment. Its experience of its environment is its reality and its experience is contingent upon its degree of (self-organization) existence. The system creates, or constructs, its reality so that its identity and existence endures.

This contrasts strongly with the current Artificial Intelligence approach to the construction of autonomous systems. For example, computer vision and robotics address many of the issues which are relevant to the design of artificial autonomous, adaptive and anticipatory, systems. Image understanding systems attempt to understand the physical structure of the local environment with the express purpose of allowing robotic systems to interact with that environment. From the A.I. perspective, vision is a process of abstraction which is primarily concerned with the construction of representations of the absolute (and true) reality that exists without. This is strongly reminiscent of the ontology of Lockean Realism which we discussed in the first section. Robotics, on the other hand, is concerned with the manipulation of the real environment which is *abstracted* in the representations formed by the perecptual apparatus. Its ability to effect useful action hinges on the validity of the representations and on the accuracy of the representations. From the point of view of accuracy, there have in the past been some 'technological' problems with achieving acceptable performance. However, from the point of view of validity, the central problem in trying to design autonomous systems which are based on the type of representational vision systems described above is that the designer is acting as an implicit *homunculus*, an interpreter, at the perception/action interface: he or she decides on the representations which will be used and on the rules which will be invoked in response to certain perceptual (representational) stimuli. While this approach is ideal for the construction of goal-oriented systems which function in an environment which can be specified *a priori* it does not, and cannot, address the problems which arise when adaptive, self-determining, autonomous systems are required. The presence of this homunculus is anathema to autonomous sytems. The conventional representational A.I. approach may be adequate for perceptual/robotic control systems (and I include stimulus-response type 'autonomous' navigation and robotic manipulation in this category) but they are totally at variance with the the structural, organizational, and be-

havioural plasticity which is fundamental to autonomous systems. We would argue that the implicit incorporation of an homunculus through the *a priori* specification of object (i.e. world) representations and manipulation strategies so strongly prejudices the structure of the system that the likelihood of developing a truly autonomous system is quite low. However, by addressing directly the organizational principles by which autonomous systems arise — rather than the representations which we as system designers believe to be appropriate to autonomous systems — the likelihood of creating truly autonomous systems is increased. The problem which then arises is how such autonomous systems can be imbued with a goal-oriented behaviour which reflects the requirements of its designer. This remains an open question. First we must develop a formal science of autonomous systems and self-organization.

4 Systematics and Relativistic Ontologies

4.1 Bennett's Natural Philosophy

4.1.1 Function, Being, and Will

John Bennett, in his *magnum opus*, 'The Dramatic Universe'[1], presents an ontology which clearly reconciles the inadequacies of idealism and realism. In Bennett's natural Philosophy, *experience* is the given totality. Whatever sense we make of reality and existence, it arises through, and only through, our experience, if it is to be at all meaningful. Bennett asserts that the question 'Of what stuff is all reality made?' is identical to the question 'Of what stuff is all experience made?' Thus, 'What exists is experience itself.' Bennett uses the word 'hylē', after Aristotle, to denote the 'stuff' of experience. Note that hylē is actually perceived, or observed, or experienced, and is thus phenomenal and not noumenal.

Bennett contends that there are three terms (or aspects) of experience: *function, being,* and *will*. Function corresponds to the knowable aspect of experience: the facts, the communicable knowledge, whereas being is unknowable but connotes the concreteness of experience: the greater the being, the 'more real' the experience and the less it is caught with illusion. Given that there are levels of being, then so too are there laws of being. These laws are 'manifestations of will'. Will is the intentionality in experience; the active element in experience.

Each of these terms in the triad of experience can be viewed in at least two ways: from a subjective and from an objective point of view. With function, the subjective aspect is *knowledge* and is related to the concept of *fact* to which we will come shortly. The objective view of the functional aspect of experience is behaviour: the dynamical appearance implicit in the experience.

As Bennett points out, a similar description of these two views on being is fraught with difficulty, for the language which we use to communicate is a vehicle, by and large, for imparting fact and knowledge. Being is not factual nor

knowlable and so the language is inadequate to the task. Nonetheless, we can try since being, though not knowable, is experienced and we all have had, to a greater or lesser degree, experience of the two aspects of being. The subjective aspect we call *consciousness*; it conveys the concreteness or presence we feel in an experience (and, also, the residual memory we have of that experience, subsequently). The objective aspect of being is referred to as *materiality*: the lower the level of being, the higher the level of materiality inherent in the experience. This will become a little clearer later on when we discuss the relationship of being to potentiality and potency. For the present, note simply that being connotes potentiality and, hence, virtuality. If a high level of being, from an objective standpoint, is equivalently a high level or potentiality and virtuality, it is thus less actual and less material.

The words to express the objective and subjective aspects of *will* are even harder to find than those for being. Recall that will is the intenionality in experience; the motive or active force. Bennett describes it as 'that which uses the functions under the conditions created by consciousness'. Or rather, that which allows the use, since will does not *do* anything. If we use the word *understanding* in the strong and deep sense of apprehending the meaning of a thing in all its aspects — why it is, what it is, and how it acts — we can see that this word understanding captures the subjective aspect of will and it is this subjective aspect of will in experience which truly allows us to understand 'the intrinsic character of a situation'. If understanding conveys the 'way things are' in the subjective aspect, then the objective aspect of will is *law*: the way things must be.

4.1.2 Phenomena

From the fundamental triad of experience — function, being, and will, Bennett proceeds to devlop a very intuitive presentation of *phenomena*. He begins with *knowledge* which he states is 'the adaptation of behaviour to function'. That is, there is the functional aspect of our experience and there is a concomitant behaviour on our part in this experiencing. We adapt our behaviour to the experience, and knowledge captures the resultant correspondence between the two. In this sense 'knowledge is the ordering of function' and *fact* then is the content of knowledge, both actual and potential. Thus, 'fact is the experience of functional order'. It is all that is known and all that can be known.

It is at this point that Bennett makes the very important distinction between *fact* and *value*. There is nothing in fact, in particular, or knowledge, in general, that captures the essence of a (hypothetical) assertion that one thing is 'better' than another. Such an assertion is a value statement and does not belong to the functional aspect of experience: value is something one is conscious of and has to do with being and will. Nonetheless, it is worth remembering that function and being stand in counterpoint: experience involves both and one cannot have one without the other, in whatever relative measure. To paraphrase Bennett,

facts correspond to the actual content in experience while values correspond to the potential content.

All experience has aspects of function, being, and will and we can view the experience from any one of these perspectives. If we are concerned primarily with the functional aspects, we can use the word *phenomena* to stand for experience at a given state of consciousness (or being) and, thus, 'fact is the result of reducing phenomena to knowledge.' This contrasts with the situation of experience, in general, which is not contingent upon any particular state of consciousness or being. By referring to a level of being which corresponds to an average human being, we thus distinguish the contingent experience by referring to it as phenomena. In essence, experience is conditioned by (the level of) consciousness and becomes phenomenal; the functional aspects of phenomena are facts. Fact may then be represented by, e.g., language (natural or formal) to allow us to search for and discover new knowledge. It can be seen here that, in this scheme, both the subjectivity of idealism and the objectivity of realism are both adequately captured in this relativistic framework.

4.1.3 The Framework Determining-conditions

The form in which we experience phenomena is called *framework*. Bennett refers to four *framework determining-conditions* which define the form of our common experience. These are eternity, time, hyparxis,[4] and space. Eternity has the phenomenal characteristic of potentiality and intensity of being; time: actualization and irreversibility; hyparxis: ableness-to-be and cyclicity; and space: presence and coexistence. Thus, Bennett is postulating the reality of two additional degrees of freedom, or dimensions, of any existing entity: eternity and hyparxis. Eternity reflects the real existential status of the potential — the coexistence of uninstantiated instances or entities — which is manifested in being and, importantly, the continuum of being (or intensity of being). But while the potential inherent in being is real, whether or not it is actualized is dependent on the status of the experience or entity in hyparxis: thus, its 'ableness-to-be'. Bound up in the two framework determining-conditions of time and eternity, there are the two opposing aspects of actuality and potentiality. Any given experience, or phenomenon, is determined by its status in these two aspects of reality. Bennett uses the term *virtue* to describe the ratio of actuality to potentiality in a system or entity. A system which is wholly virtual is one of pure potential and is not (yet) actual; a system of zero virtue has *no* potential what so ever and it can never change or alter. It is, in effect, in thermodynamic equilibrium in a state of maximum entropy.

Just as with the framework of space, where we speak of entities being separated by a spatial interval, and the framework of time, where we speak of a

[4] *Hyparxis* is derived from the Greek word $\vartheta\pi\alpha\rho\chi\epsilon\iota\nu$, a term used by Aristotle to mean 'the power to exist, as distinct from existence itself'.

temporal interval, so too with eternity, there is an interval which separates entities with distinct sets of potentialities. Bennett chooses the word *apokrisis* (from the Greek verb $\alpha\pi\omega\kappa\rho\iota\nu\omega$ — to separate into two levels) to denote this interval. As we have suggested previously, the ontological status of physical and chemical systems or entities differs from that of life forms in the status of its being. Thus, 'the apokrisis of a living organism is that which distinguishes it from a physico-chemical mechanism.'

Perhaps the best way to summarize the foregoing text on the framework determining-conditions of space, time, eternity, and hyparxis, is to quote Bennett directly:

> *Phenomena are ... the experience of the ordinary man in his ordinary states of consciousness [and] the phenomenal world is present in space, successive in time, potential in eternity, and held together by its hyparchic recurrence.*

Two issues are noteworthy in this discussion of phenomena. First, Bennett states that phenomena are relative to our ordinary level of consciousness and thus have no fixed status. This is exactly the same thing as saying that man is constructivist and that his phenomenal understanding of the world is contingent upon his ontological status, determined by his level of being. Second, an understanding (as opposed to a 'knowing') of the phenomena requires, in addition to fact and knowledge, a corresponding apprehension of the levels of being and the forms of will.

4.1.4 The Stratification of Existence

We have now arrived at the point which we set out to reach at the beginning of the section: a framework for a coherent relativistic ontology. Bennett refers to this as the 'postulate of the stratification of existence' and it is none other than a manner of segmenting (or labelling) the continuous spectrum of existence and being to which we have alluded so much in the above. Significantly, it is the concept of eternity which allows us to represent to ourselves this stratification by providing us with the framework determining-condition for potentiality which characterizes the level of being of an entity. Bennett uses the word *potency* to denote the assembly of potentialities within a given type, or class, of entity.[5] It thus identifies the limits of the possible self-realization of entities of that class: the 'maximum degree of individuation accessible to member of a given class of entities'. Potency, then, is the criterion of level of existence.

We are now in a position to re-present, with a minimal amount of comment, Bennett's stratification of existence.

[5]So far, we have been using the term *entity* to denote any system or thing which exists at any ontological level. We have taken a slight liberty in this since in Bennett's exposition the word *entity* refers to a thing or system which is referred to a specific potency. Bennett himself uses the word *whole* to connote the general idea of a thing or a system at any given ontological level.

Existence is divided into three chief domains of sub-animate, animate, and supra-animate existence. These are called the *hyponomic*, the *autonomic*, and the *hypernomic* modes of existence, respectively. Within each of these modes there are four levels of existence[6] and thus there are twelve levels in total. Within each level, there is, of course, a gradation of the degree to which the entity exemplifies that level of existence. The spectrum of existence, then, is a gradual one. Before identifying each of the levels of existence, a short comment on each of the modes is in order.

The class of entities which correspond to the hyponomic mode are essentially passive in all their relationships, both inner and outer. This is the domain of 'things'. The class of entities which correspond to the autonomic mode have, to a greater or lesser degree, a sense of 'self' or individuation. They are able to maintain a balance of reconciliation between their inner and outer relationships and, in particular, it is in this balance that the identity of the entity arises, *through itself and by itself.* The four levels of autonomic existence correspond, then, to four distinct levels of autonomy. All autonomic systems are living systems. Entities in the hypernomic mode of existence act as originating active sources for external relationships.

Bennett's stratification of existence is reproduced below, *verbatim.* Following that, a table is reproduced from *The Dramatic Universe, Vol. 1,* which sets down a systematic classification showing the branches of natural science comprised is Bennett's relativistic ontology. This table summarizes his *Universal Systematics of Natural Philosophy.*

A. Hyponomic Dominant. The Physical World — Things

A1. *Unipotence — Hypothesis of Existential Indifference*
There is a class of occasions,[7] the laws of which are independent of the nature of the existents that participate in them.

A2. *Bipotence — Hypothesis of Invariant Being*
There is a class of occasions in which entities behave as if they were exempt from mutual interaction and were self-identical and invariant with respect to all four determining-conditions.

A3. *Tripotence — Hypothesis of Identical Recurrence*
There is a class of occasions in which entities behave as if they were exempt from any but reversible interactions and were subject only to cyclic changes in their inner constitution.

A4. *Quadripotence — Hypothesis of Composite Wholeness*
There is a class of occasions in which entities enduring in time behave

[6]Each of the four levels in a given mode of existence are distinguished by their ableness to be, i.e. their hyparchic existence.

[7]A *situation* is a fact, irrespective of whether it is possible or not. An *occasion* is a possible situation and can be either actual or potential. An *actualization* is an occasion which is accessible to sense perception.

as if subject to both interaction and change and yet remain wholly passive in their inner and outer relationships.

T1. *Transitional Hypothesis of Active Surface*
There is a class of occasions in which entities behave as if their wholeness were maintained by a pattern of potentialities that enables exchanges of *hylē* to take place across their boundary without loss of identity.

B. Autonomic Dominant. The Animate World — Life

B1. *Quinquepotence — Hypothesis of Self-Renewing Wholeness*
There is a class of occasions in which the duration of existence in time is prolonged by the renewal of potential energy at the expense of the environment.

B2. *Sexipotence — Hypothesis of Reproductive Wholeness*
There is a class of occasions in which self-renewing entities can reproduce outside their own surface other entities similar to themselves.

B3. *Septempotence — Hypothesis of Self-Regulating Wholeness*
There is a class of occasions comprising entities able to maintain and regulate a functional balance within their own enclosed surface or skin.

B4. *Octopotence — Hypothesis of Self-Directing Wholeness*
There is a class of occasions characterized by the presence of self-directing entities able consciously to choose between alternative lines of actualization in time.

T2. *Transitional Hypothesis of Biospheric Wholeness*
There is a class of occasions in each of which one total living whole is associated with the active surface of a planet.

C. Hypernomic Dominant. The Supra-Animate World — Cellestial Existence

C1. *Novempotence — Hypothesis of Sub-Creative Wholeness*
There is a class of occasions in which entities can exert an affirming force towards life without being themselves independent wholes.

C2. *Decempotence — Hypothesis of Creative Wholeness*
There is a class of occasions in which entities atomic in nature exercise a free creative power within their own presence.

C3. *Undecimpotence — Hypothesis of Super-Creative Wholeness*
There is a class of occasions in which entities — not themselves autocratic — are nevertheless manifestations of the supreme affirming power.

C4. *Duodecimpotence — Hypothesis of Autocratic Wholeness*
There must be a whole of wholes that is hypernomic for all its subordinate parts. This whole is the universal affirmation.

4.2 The Spectrum of Autonomy

The stratification of existence offers more than a relativistic ontology. Recall that as experience progresses along the scale of being, i.e. along the ontological spectrum, from that with no potential to that with greater potential, the experience becomes more and more real: more concrete. In exactly the same way, entities with greater potency are more concrete and real: they are more and more themselves and 'can be recognized by reason of what it is in itself and for itself and not by reference to the environment in which it is situated'. This quite clearly echoes our earlier discussion of autonomous systems as entities which, though existing in a context and in an environment, are self-specifying and self-determing. Thus, in the concept of a spectrum of ontology, of being and existence, there is also, correspondingly and concomitantly, the concept of *a spectrum of autonomy*.

In our case, we are interested in the four levels of existence in the autonomic mode; these correspond to what we understand by autonomous systems. We note that, consequently, there are four types of autonomous system:

1. Self-renewing autonomous systems.
2. Self-reproducing autonomous systems.
3. Self-regulating autonomous systems.
4. Self-directing autonomous systems.

In tables 1 and 2 above, each of the twelve levels of existence corresponds to a unique *category*. Bennett begins the presentation of his Natural Philosophy by introducing *categories* which are the fundamental elements of experience and which have a general or universal character. Bennett names twelve categories. Each of the categories, numbered one to twelve, requires that same number of terms be present in order for the true characteristics of that category to be fully captured or exhibited in its systemic formulation. The number of terms define the *order* of the system or entity. It is significant that each additional term must import into the experience the appropriate characteristic and thus must be 'compatible' with the terms that went before. This is a key issue, for it provides us with the boundary conditions of which we need to take cognizance when investigating an entity of a particular potency.

In the case of particular interest here, we note that the four types of autonomous entity, ranging from quinquepotent to octopotent systems, require five, six, seven, and eight terms, respectively, for their formulation. It remains

Potency	*Hypothesis*	*Science*	*Category*
Unipotent Entities.	Existential Indifference.	The framework sciences. Geometry. Arithmetic. Logic. Kinetics of uniform motions. Four-dimensional physics	Wholeness
Bipotent Entities.	Invariant Being.	The polar sciences. Forcefields. Dynamics Electro-magnetism. Corpuscles. Light. Five-dimensional physics	Polarity
Tripotent Entities.	Identical Recurrence.	The physical world. Behaviour of rigid and plastic objects. Ultimate particles Six-dimensional physics	Relatedness
Quadripotent Entities.	Composite Wholeness.	Atomic nuclei. Properties of matter. Exchange processes. Chemistry and Mechanics. Thinghood.	Subsistence
The First Transition.	Active Surface.	Colloid sciences. Polyphase systems. Interaction of levels. Proteins and nucleic acids. Enzymes and catalysts.	

Table 1: The Universal Systematics of Natural Philosophy.

Potency	*Hypothesis*	*Science*	*Category*
Quinquepotent Entities.	Self-renewing Wholeness.	Sub-cellular life. Viral science. Biochemistry.	Potentiality
Sexipotent Entities.	Reproductive Wholeness.	The cell world. Cytology. Protzoology. Embryology.	Repetition
Septemipotent Entities.	Self-regulating Wholeness.	The metazoa. Biological sciences. Development and growth. The Phenomena of birth and death.	Structure
Octopotent Entities.	Self-directing Wholeness.	Individuation. Psychology. Herd behaviour. Organic sciences.	Individuality
The Second Transition.	Biospheric Wholeness.	The biosphere. Ecology and genetics. Origin of species.	
Novempotent Entities.	Sub-creative Wholeness.	Existence beyond life. The planets.	Pattern
Decempotent Entities.	Creative Wholeness.	The sun and the stars. Functional freedom. Creativity. The solar systems. Cosmic individuality.	Creativity
Undecimpotent Entities.	Super-creative Wholeness.	The galaxies. The universal Transformation.	Domination
Duodecimpotent Entities.	Autocratic Wholeness.	The knowable universe. The universal order. Cosmology.	Autocracy

Table 2: The Universal Systematics of Natural Philosophy (continued).

to identify these terms and their attributes when attempting to develop a simulation of an autonomous entity. This is the subject matter of the next section.

To conclude this section, let us reiterate and emphasise one point. We have identified a relativistic ontology, exhibiting a stratification of existence, which is characterized by a spectrum of potentiality (the eternal framework determining-condition) and 'ableness-to-be' (the hyparchic framework determining-condition). This allowed us to identify a spectrum of autonomy and, importantly, the boundary condition which we must take into consideration when investigating the four normal forms of autonomous existence, i.e., the number of terms which an entity requires in its systematic formulation. However, in all of that we have discussed, we have never stepped outside the domain of phenomena and thus all that has been said is bound to the potency which we, as humans, exhibit in our ordinary state of being.

5 Recapitulation

To conclude, a short recap on the issues we have discussed may be helpful to clarify the position at which we find ourselves upon completion of this essay. We began by identifying one of the key issues in autonomy: that autonomous systems, despite the apparent paradox, are defined in a context and that it is the mutual relevance of the autonomous system and its context, and the mutual specification of the two, by which autonomous systems arise and must be understood. This led us to consider the most fundamental, and meaningful, of contexts: the nature of reality and existence.

After a brief tour through the main philosophical positions on being and existence — ontology — we argued that the ontology one adopts prejudices what one conceives as being possible and actual. In particular, we argued that the pervasive realistic ontologies of, e.g. Locke or Moore, with their 'binary-valued' attributes of existence or non-existence, irrespective of the observer, does not allow for an adequate treatment of autonomous systems. We dubbed this paradigm 'scientific ontology' as it pervades the thinking of so many of modern scientists. We looked too at the more esoteric idealistic ontologies of, e.g. Berkeley or Kant, with their explicit dependence on the observer. We concluded that the distinction between the phenomena and the noumena in idealism offers at least scope for progress in that it does not adopt a pejorative standpoint on what might be the true noumenal nature of reality, as opposed to our perceptions, and experience, of it. We then argued that a relativistic ontology, borrowing greatly from Kant's idealism but also taking on board the validity of realism and the necessity of dealing with phenomenology and personal experience, is what is required for a sound foundation of autonomous systems.

Allowing a relativity in ontology results in a spectrum of being and existence and does away with the 'binary-valued' view-point on existence. It is this spectrum of existence — more or less-real entities — which, in turn, allows for a

possibility for entities to have one or other level of existence or being. We then identified *organization* with this scale of existence or, rather, we idenified it as an 'indicator' to a level of existence.

We concluded that since the development, or actualization, of the potential for existence at a certain level, specifically for existence at an autonomous level, concerns the noumenal aspects of entities, and is not at all contingent upon the phenomemology of humans or any other cognitive entity, then this actualization cannot be deterministically invoked by a 'third party' and requires *self-actualization* or *self-organization*. Such self-organizing autonomous systems are effectively life-forms. However, the possibility still exists for the *simulation* of autonomous systems through self-organization in our phenomenological domain, rather than the self-organization of life-forms in a noumenological domain.

We looked at the ramifications for autonomous systems of the effective combination of realism and idealism in this relativistic ontology and the consequent constructivist nature of perception and cognition. This led to the identification of a pathalogical flaw in the development of autonomous systems using conventional representational information-processing approaches: the implicit homunculus.

We looked in detail at the Natural Philosophy of J.G. Bennett, with its relativistic ontology which posits a stratification of existence. We noted that autonomous systems, as we understand them, correspond to levels five through eight, inclusive, in this ontology and thus we are presented with a spectrum of autonomy. It is important to note too that along with this ontology, Bennett presents a methodology (*Systematics*) for dealing with and understanding each of these levels. This methodology hinges upon the correlation between the ontological level and the number of terms which a system of that level must possess in order to exhibit the characteristics of that level. This led us then to consider Varela's and Maturana's concept of autopoiesis as a form of entity at the fifth level of existence — a so-called quinquepotent entity. While *Systematics* provided us with a methodology for determining the boundary conditions of a specific type of autonomous system, it is the calculus of Indications which allows us to contemplate the design of simulations of autonomous systems. We presented some preliminary results of such design, expressed again in terms of indicational forms and we developed a set of necessary conditions for the realization of autopoietic — self-renewing autonomous — systems. Although the simulation system which was described has been validated by realizing a simple allopoietic control system for target tracking, it remains to validate the organizational principles of autopoietic systems and the conditions for the realization of autopoiesis with this simulator. Once this is achieved, we can then proceed to develop simulations of autonomous systems of higher complexity, beginning with self-replicating autonomous entities.

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