

Artificial Intelligence and Nature's Fundamental Process

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Abstract

In order to address the central question at the heart of the concluding debate at the AAAI 07 Spring quantum interaction symposium, where it was proposed that other probabilistic and nondeterministic theories might replace quantum mechanics, even in relation to quantum physics, and in further explanation of our AAAI Spring 2007 paper 'How Intelligence Evolved?', we outline the derivation from first principles of what we call the universal rewrite system. For, once derived, this system has all the appearances of being nature's semantic computational machine order code, readily identifiable with a new version of quantum mechanics, and powerful predictive capabilities. These, fully detailed in the book *Zero to Infinity*, now published by World Scientific (Rowlands, 2007), especially in chapter 20, which is a joint contribution by the authors of this paper, are in total agreement with experiment so far, in particular in elementary particle physics, magnetic nuclear spectroscopy and MRI, and the DNA / RNA genetic code molecular biology. Indeed, in the earlier paper, a further identifiable version of this universal rewrite system in recognition of its descriptive quantum physical nature, is that of Dirac's bra / ket quantum mechanical formalism, where bra and ket will serve as the two creation and conserve universal rewrite system rules / productions, so showing it to describe, in the case of bosons, a Bargmann-Fock quantum field of creation / annihilation operators. It is our view, therefore, that this quantum physical universal computational rewrite system, where the nilpotent generalization of Dirac's famous quantum mechanical equation specifies the computational machine order code, describes the quantum physical system of process at the heart of nature, and that recognition of this is a necessary step in creating an artificial intelligence which has semantic, as well as syntactic features.

Introduction

In our attempts at creating artificial intelligence using digital logic, we have constructed some very powerful computing machines, ones that can, for example, outperform the best human chess players. The logic of these machines, however, is purely syntactic, and the information is merely a string of 0s and 1s; there is no semantic input, other than the interpretation of the programmer. The machines can only outperform humans

because they are dedicated to specific tasks which can be structured in this way by an interpreter who thinks in a different way altogether. Clearly the human brain does not operate using digital logic, nor does 'nature' in general. Events are not subject to an iterative series of trials of possible outcomes before nature works out the optimum strategy, as would happen in a computerized chess game. Again, we understand with great precision how many individual centres in the brain operate, but the sum of these does not appear to tell us how the brain itself works as a totality. In principle, nature has no option but to work by a recursive method, which also seems to be approximated by the action of the human brain, but so far we have only been able to develop iterative strategies to reproduce it. It looks like we will only make significant progress in this field if we can find a fundamental method or processing in nature that connects the iterative with the recursive.

However, to understand nature's most fundamental method of processing, we need to attack the problem at the most fundamental level, which is that of fundamental physics. At this level we are looking at the interactions of nature's most fundamental known units, or *fermions*, which means we need to understand the workings of quantum mechanics, the most accurate predictor of natural events ever devised. In physics, of course, there are only fermions and their interactions, bosons being part of the latter. Now, we already have a quantum mechanical description of fermions, in the relativistic Dirac equation, but it does not appear to be particularly convenient for our purpose. Standard quantum mechanics, with its awkward mathematical formalisms and mysterious 'black box' wavefunctions, gives the impression of being something like a bureaucracy which repeatedly asks you for the same information in different ways without being ready to give answers to your own questions or allowing you to find out how your information fits into an overall picture. It seems almost as though it is structured in a particular way to have a minimum degree of accessibility. Even though we can use it to find particular answers to some specific questions, we don't entirely feel that this can be how nature 'really'

operates.

But there is one version of quantum mechanics which is very different, even though it can be derived by various mathematical transformations from the standard form. It is iterative and recursive at the same time, because, by a special mathematical property, it gives us the big picture instantly at the same time as we are investigating the specific case. The opportunity is present in standard quantum mechanics where we frequently resort to the holistic concept of 'vacuum', but, because it is usually so ill-defined, the connection is never made. However, it is possible to define the concept in a way that it is precise, mathematically exact and logically satisfying, and gives us the exact link we need between iteration and recursion. This form of quantum mechanics is fermionic and necessarily relativistic, and it is based on the absolute primacy of Pauli exclusion. In effect, we construct a creation operator for a fermion, which in its simplest form is what we would call a covariant derivative, a combination of differentials in space and time with the potentials which express its interactions with the rest of the universe but without requiring the specifying of its sources.

Nothing else whatsoever is needed – wavefunctions, phase factors, amplitudes, spinors, vacuum, or even an equation – because everything required emerges directly from the operator without further input. If we structure our information in this way, nature becomes like a perfect relational database, giving a complete and unambiguous response to a query posed in terms of a key field. The reason why this is possible is because Pauli exclusion is the expression of a more fundamental concept which provides an all-embracing constraint. This is that nature works to produce zero totality at all times. So, if we imagine creating a fermion (with all its potentials, etc.) out of absolutely nothing (say as ψ), then we must at the same time create a 'vacuum' or 'rest of the universe' (as $-\psi$, a 'conjugated' state) such that the totality remains zero. In quantum mechanical terms, both the superposition of fermion and vacuum ($\psi - \psi$) and their combination state ($-\psi\psi$) are zero, and the latter condition, equivalent to the Pauli exclusion of two identical fermions ($\psi\psi$), means that the fermion amplitude must be *nilpotent*, or square to zero. (A brief account of the basis of the nilpotent quantum mechanics (first published in Rowlands, 1994) is given here in an Appendix. Nilpotents have a number of current applications in physics, especially in the BRST theory (Frydryszak, 2007, Rowlands, 2007), but it does not seem to have been established by other authors that the fermionic wavefunction actually has this underlying structure.)

Using the constraint of nilpotency at all times, for fermions in any state, means that, as soon as the operator is defined, the whole superstructure of the quantum mechanics that goes with it is defined as well, for the

operator uniquely defines a phase factor on which it acts to produce an amplitude which is nilpotent. It also means that the entire universe or 'environment' in which this property becomes possible is defined as well. Although we may not know the detailed structure of how the environment is constructed, we know exactly what its totality must be. The series of potentials used to construct the operator may be iterative but the immediate zeroing gives us recursivity as well. A single fermion can only be 'created' if we simultaneously create the rest of the universe as a kind of reverse image, whose structure is completely defined. We don't have to know how to construct the universe, only that it must have been so constructed. This quantum mechanics is not just a hoped-for ideal. It is already in place, solving previously worrying anomalies, performing analytical calculations never previously attempted, and generating much of the Standard Model or particle physics automatically from first principles. It is not only simpler and more transparent than other forms of quantum mechanics (including nonrelativistic versions) but also more powerful. However, it requires a particular structuring of the information to make this possible – a particular 'code' which makes the fermionic object exactly symmetrical with its universal image. We achieve recursion and holism by finding a special form of iteration and specificity which is its image.

There seems to be every reason to believe that this is the way nature would choose to operate at a fundamental level. So, does it indicate a more general description of process, not confined to physics? It is the aim of the universal rewrite system to specifically answer this question. Such a system, if valid, must operate before number, before algebra, and before space and time and other 'physical' concepts. Here, we have proposed exactly such a system, privileging zero totality, and producing an automatic connection between the part and the whole through an analogue to the nilpotency condition, which works out in physics as Pauli exclusion. The rewrite system is structured to operate at all levels from any starting point, and our investigations into other areas where recursion seems to be significant in practice suggest that it provides a universal pattern in nature, a 'machine order code'. We believe, for example, that the same pattern of algebra / geometry can be seen in biology in the way the genetic code works, and we can imagine that there is, in general, a fractal pattern of emergence, a ladder or staircase leading from simpler to more complex systems, whose 'holistic' aspect is always determined by the need to maintain zero totality. We also believe that it predicts thermodynamic conditions (e.g. the quantum Carnot engine) that can be applied on many scales, and that existing work on such things as quantum holography and MRI imaging can be meaningfully incorporated within this paradigm.

The universal rewrite system

The meaning of a computer program is not in the digital code it presents to the hardware for processing but in what it represents to the programmer. Our mental understanding operates by some other system. We have asked ourselves: what makes human reasoning not merely syntactic but semantic, as is manifestly the case, in our natural language abilities? What is the nature of the human brain's machine order code that gives it these semantic capabilities? In our view, the answer lies in a process which operates at the heart of nature, which we derive from first principles and call the universal rewrite system, and which, once derived, has all the appearances of being nature's machine order code. For the rewrite system generates a new version of quantum mechanics, with powerful predictive capabilities in total agreement with experiment so far, which has at its basis the idea of a *nilpotent* quantum state; that is, one that is a square root of zero.

This entirely novel bootstrap approach begins with the concept of the computational rewrite system, where a finite alphabet (and its relationships) symbolizes the form of the operational rules necessary to the execution of the program to be devised. Such a symbolization sets no limits to the form of these operations (syntax or semantics) except that they are physically possible, when presented to the 'hardware', so allowing the use, for example, of noncommutative, anticommutative or even nonassociative operations that known quantum mechanical verification says are indeed physically possible. It is certain that, if these operations set natural computational systems apart from their digital counterparts and offer evolutionary advantage, then evolved living mechanisms like the human brain could indeed be using them.

The universal rewrite system is a pure description of process based on the idea that the totality of the universe at all times is zero – *nihil ex nihilo fit*. The system has a fractal structure in that its nilpotence takes the same form at all levels. You can begin at any point in the hierarchy and it will look the same. As outlined in our previous AAAI paper and fully set out in an extensive book, *Zero to Infinity* (Rowlands, 2007), the full rewrite structure is rewritten at a higher level of molecular complexity as the genetic code in the form of DNA / RNA and in the form of the neural mechanisms which support the human brain's semantic natural language capabilities. To describe what is happening to any part of the system, we must describe what is happening in the rest of the universe as well. We only comprehend the part by connecting it instantly to the whole. This shows that the semantic code for the whole of nature is holistic, and adds a completely new dimension to the mind / brain problem.

The nilpotent universal computational rewrite system or NUCRS, to give its full title, was, as stated, originally

developed from the more conventional type of rewrite or production system used in computing theory, in which we define an object, usually in the form of a string of characters, and then use a set of rewrite rules to generate a new string, which represents an altered state of the object. (Rowlands and Diaz, 2002, Diaz and Rowlands, 2005.) Here, it was found that a more universal type of rewrite system could be envisaged in which the alphabet, or set of characters from which the object is generated, rather than being fixed, would be *extended* at every application of the rewrite procedure. The results of this procedure, and its extensive application to areas of computing and information theory, mathematics, physics and biology, outlined in our previous AAAI paper 'How Intelligence Evolved?' (Marcer and Rowlands, 2007), are now included in *Zero to Infinity*, for, though the idea above is simple in principle, it requires lengthy treatment to establish its full logical basis and the full range of its potential applications. Moreover the existence of the symbolization of the nilpotent alphabet 'devoid of human baggage', together with the requirement that the defined operations to be derived are physically possible, implies the existence of an external physical reality completely independent of human perception, the principle that Tegmark calls the external reality hypothesis (Tegmark, 2007 a, b).

To give a brief idea of how it operates, we imagine trying to describe a system whose totality is absolutely zero (that is, in conceptual, not purely numerical, terms). However, the zero concept is infinitely degenerate (for example, topologically) and, as soon as we have we devised one conceptualisation of it, we have to extend it for another. The process we will see is something like privileging cardinality at all times over ordinality (or ordinality over individual number). Let us call the zero totality at any point in this sequence the 'alphabet', and anything which is less than the entire alphabet a 'subalphabet'. We are not allowed, at this point, to use number-based mathematics, or any physical concept, like (to use Tegmark's words) 'the human baggage terms' space or time. So we will imagine a process of 'concatenation', without attempting to give it an exact meaning. Let us suppose that we define two processes: *conserve*, which says that an alphabet concatenated with any subalphabet, yields only itself; and *create*, which says that an alphabet concatenated with itself automatically generates a new (extended) alphabet. This is merely for descriptive convenience, for we can assume that they are simply different ways of looking at a single process.

Now, whatever an alphabet may contain, say we call it R , if this is nonzero, then we cannot have zero totality without some concept of 'conjugation' R^* of R , whatever this may mean. So, we could write down a minimum condition for an alphabet to be something like (R, R^*) . To maintain the zero totality, the conjugation must be *within*

the alphabet; R , for example, is not an alphabet. If, again for convenience, we write ‘conserve’ as \rightarrow , we can then say that the ‘subalphabets’ of (R, R^*) must concatenate with it to produce only (R, R^*) . So, if we say $R(R, R^*) \rightarrow (R, R^*)$, then we must have $R^*(R, R^*) \rightarrow (R^*, R)$, which is the same totality as (R, R^*) , but distinguishes R and R^* , so that $RR \rightarrow R$, $R^*R \rightarrow R^*$, and $R^*R^* \rightarrow R$. When, however, we apply ‘create’ and concatenate (R, R^*) with itself, we must create a new zero totality (and, hence, conjugated) alphabet, whose subalphabets do not produce anything new by concatenation with it. We have to guess the form of the new alphabet, and then use ‘conserve’ to check that our guess is consistent with the process. The obvious guess is something like (R, R^*, A, A^*) , but with the new terms distinct from R and R^* , to ensure that the extended alphabet is actually new. If we now apply ‘conserve’ to this new alphabet, we find that we can concatenate with R and then R^* to produce first the original alphabet, and then the original alphabet with the R and R^* , and A and A^* terms switched round. Then, the concatenation with A and A^* must produce further changes in the order, if A and A^* are to be distinguished from R and R^* , but no new terms must be introduced, so the totality remains the same. We find that we can do this if $AA \rightarrow R^*$, but $AA \rightarrow R$ will be impossible if A is to be distinguishable from R . At the same time we find that $A^*A^* \rightarrow R^*$ and $A^*A \rightarrow R$, which means that A and A^* can be distinguished.

So far, our guesses appear to have been successful, but our intuition fails us when we apply ‘create’ to (R, R^*, A, A^*) because an alphabet of the form (R, R^*, A, A^*, B, B^*) does not lead to a successful application of ‘conserve’ if we concatenate with its subalphabets. We quickly find that we obtain terms like AB and AB^* which cannot be contained within the alphabet (R, R^*, A, A^*, B, B^*) . So, we make the next best guess and try $(R, R^*, A, A^*, B, B^*, AB, AB^*)$. Now, the concatenation of this with its subalphabets is straightforward until we try $AB(R, R^*, A, A^*, B, B^*, AB, AB^*)$ and $AB^*(R, R^*, A, A^*, B, B^*, AB, AB^*)$. Here, we find, that we are obliged to take either

$$\begin{array}{l} AB AB \rightarrow R \quad \text{and} \quad AB AB^* \rightarrow R^* \\ \text{or} \quad AB AB \rightarrow R^* \quad \text{and} \quad AB AB^* \rightarrow R \end{array}$$

to preserve the integrity of ‘conserve’. But, if A and B are to be distinguished, then only the second option is possible. We can identify this as a form of *anticommutativity*, and see that, if A and B are anticommutative, in this way, with each other, then they can only be anticommutative, additionally, with AB , and not with any other term. So, the next terms in the series, say, C, C^* , must be *commutative* with A, A^* and B, B^* . But these terms can be described as unique because C will have a unique anticommutative partner D to define its existence, and we can now continue in this way indefinitely because each new term in the series has an identity different from every other, because it has a unique partner to which it is anticommutative. In addition,

we have introduced a concept of *discreteness* through our definition of a series of closed sets. Because of an analogy that we will later establish with mathematical algebra, we can describe the process in which new commutative subalphabets like A and C are introduced as *complexification*, and the one in which their anticommutative partners (here, B and D) first appear as *dimensionalization*.

Now, though we have not assumed the prior existence of a mathematics based on the natural numbers, our infinite series of identical but distinct anticommutative partnerships has exactly the same properties as the series of units used in binary arithmetic, and so, in this sense, we have created a natural numbering system spontaneously and in a totally abstract way. We have also created a structure that becomes naturally repetitive at the fourth alphabet, as the alphabets extend by the successive processes of conjugation, complexification and dimensionalization, followed by indefinite repetition of the processes of complexification and dimensionalization. If we were to express the alphabets in terms of group structures, we should find that the successive structures would require groups of order 2, 4, 8, 16, 32, 64 ..., and to incorporate the first four alphabets as independent structures, containing all three fundamental processes plus repetition, would require a group structure of order 64.

While the first four alphabets require eight basic ‘units’ (doubling to sixteen by conjugation), the group of order 64 requires only five combinations of these acting as generators. The classic way to obtain these is to apply the three units obtained from one of the anticommutative partnerships, say A, B, AB or C, D, CD , to the remaining five, simultaneously applying to them the mathematical structuring we have obtained by generating these partnerships. Now, though we deliberately avoided using mathematics directly, and specifically numbering, until we were able to generate it, we now have the basis, in this combined system, for defining the units of the mathematics applicable to all the alphabets, specifically the *algebras*, produced by this system of generators. Essentially, with this structuring, the first alphabet generates real scalars (units ± 1), the second alphabet introduces imaginary scalars or pseudoscalars (units $\pm i$), the third leads to quaternions (units $\pm \mathbf{i}, \pm \mathbf{j}, \pm \mathbf{k}$) and the fourth to multivariate vectors, Pauli matrices or complexified quaternions (units $\pm \mathbf{i}, \pm \mathbf{j}, \pm \mathbf{k}$). (The alphabets themselves, of course, which are undefined in terms of counting units, will not be defined by the units imposed upon them, but can be more correctly seen as generating values anywhere on the real number line.) The infinite series of alphabets becomes a form of Clifford or geometrical algebra, while the set of eight units $(1, i, j, k, \mathbf{i}, \mathbf{j}, \mathbf{k})$ combined produces the 64-component Dirac algebra of relativistic quantum mechanics. The same algebra, however, is produced by

five terms of the form $(i\mathbf{k}, \mathbf{i}, \mathbf{j}, i\mathbf{k}, \mathbf{j})$ and this (or any equivalent pentad set) is the simplest set of generators for the whole group. The five terms can be identified further as the five gamma matrices of the algebra used in the Dirac equation. At the same time, ‘concatenation’ can be interpreted, for an alphabet with this *numerical* structure, as algebraic multiplication, and the process leading to a new ‘creation’ as being equivalent to a squaring operation.

Now, physics at its most fundamental level appears to use parameters with the characteristics of the first four alphabets, which in contemporary scientific language we call mass (in the form of mass-energy) (scalar), time (pseudoscalar), charge (quaternion), and space (multivariate vector). The formation from these of the pentad set $(i\mathbf{k}, \mathbf{i}, \mathbf{j}, i\mathbf{k}, \mathbf{j})$ breaks the symmetry of the eight basic units to create the new quantities which we describe as quantised energy (E), quantised momentum ($\mathbf{p} = \mathbf{i}p_x + \mathbf{j}p_y + \mathbf{k}p_z$) and rest mass (m). It also breaks the symmetry of the original quaternion units associated with charge $(\mathbf{k}, \mathbf{i}, \mathbf{j})$ to create the weak, strong and electric units of charge and associate them respectively with pseudoscalar, vector and scalar properties. The most significant fact, however, is that it now becomes possible to define an alphabet in numeric form with the structure $(i\mathbf{k}E, \mathbf{i}p_x, \mathbf{j}p_y, \mathbf{k}p_z, \mathbf{j}m)$ as leading, by squaring, to a numerically zero new ‘creation’. That is, if $(i\mathbf{k}E + \mathbf{i}p_x + \mathbf{j}p_y + \mathbf{k}p_z + \mathbf{j}m)$ squares numerically to zero or becomes ‘nilpotent’, by choice of real number values for E , p and m , then the process of creation of new alphabets will be truncated by all the higher value alphabets equating numerically to zero. Such an alphabet can then be applied to the whole of nature, as containing on an equal footing and independent basis all the infinite series of alphabets generated by the first alphabet creation.

Now, it can be imagined (once we have incorporated all the sign options) that, if $(\pm i\mathbf{k}E \pm \mathbf{i}p_x \pm \mathbf{j}p_y \pm \mathbf{k}p_z + \mathbf{j}m)$ or $(\pm i\mathbf{k}E \pm \mathbf{i}\mathbf{p} + \mathbf{j}m)$ is taken as a fundamental unit of physical nature, with all the necessary information packaged – let’s call it a fermion – then the rest of the zero totality from which it is extracted – let’s call it vacuum – is of the form $-(\pm i\mathbf{k}E \pm \mathbf{i}\mathbf{p} + \mathbf{j}m)$, and their combined state will be of the form $-(\pm i\mathbf{k}E \pm \mathbf{i}\mathbf{p} + \mathbf{j}m)(\pm i\mathbf{k}E \pm \mathbf{i}\mathbf{p} + \mathbf{j}m) = 0$. In effect, we have the fundamental rule of the nilpotent calculus, equivalent to Pauli exclusion. It becomes even more powerful when we develop the ideas further to express $(\pm i\mathbf{k}E \pm \mathbf{i}\mathbf{p} + \mathbf{j}m)$ as a quantum operator, an expression of fermion creation (incorporating in E and \mathbf{p} whatever field terms, etc., are necessary for the creation of the fermion in that state). Then we find that we have no need of an equation or a wavefunction, or a great deal of the apparatus of conventional quantum mechanics. The operator, once defined, will *uniquely* determine the phase factor as that which will create a nilpotent amplitude.

The significance of universal rewrite

Applications of the nilpotent universal computational rewrite system (NUCRS) beyond fundamental physics are extensive and can only be given in outline here. They are, however, very extensively detailed and set down in *Zero to Infinity*, based on previous extensive refereed published research. A particularly significant application is an extension of the concept of ‘Intelligence’. A definition of Intelligence by which a sentient being may make sense of the Universe is described in ‘How Intelligence Evolved?’ (Marcer and Rowlands, 2007) It predicts, as the result of a quantum thermodynamic evolution, a staircase of novel states of matter, each of which is called ‘a phaseonium’ in the quantum thermodynamic Carnot engine (QCE) single heat bath model of Scully et al. (2003). This staircase of increasing 3D structural complexity (in excellent agreement with experiment), begins from the Universe’s origin, where a spontaneous symmetry breaking of the void (Rowlands, 2004) leads to the creation of a Standard Model of elementary particle physics and 3+1 relativistic space-time cosmology. Principal subsequent steps predicted are those of the standard elements of the ‘periodic table’ and the standard DNA / RNA genetic code of molecular biology, which today includes encodings for intelligent sentient beings like ourselves, and, it may be inferred here, of consciousness as a novel quantum state of matter of the human brain, i.e. a phaseonium.

To describe ‘a free of all initial assumptions’ essential criterion for the origin of a Universe as a theory of natural process including DNA / RNA living systems (and, hence, of sentient beings with natural language and mathematical capabilities), it is symbolized by just one symbol, conceptually representing nothing / the void initially, but which stands for an infinite alphabet symbolizing the steps / stages of the staircase of its subsequent evolution. The definition / framework for this evolution is, as we have seen, a generalization of the concept of traditional computational rewrite systems (with a fixed or finite alphabet which defines their semantic computational language). It ‘adds’ a new symbol to the initial symbol representing nothing, by means of a create operation, subject to a conserve / proofreading operation. That is, this bootstrap process examines the effect of each new symbol on those that currently exist to ensure ‘a zero sum’ again, in such a way that at each step a new symbol or sub-alphabet of the infinite alphabet is created.

Zero to Infinity unambiguously identifies the staircase of increasing 3D geometric structural complexity as the result of a quantum thermodynamic evolution, where further principal steps in the evolution of sentient beings, including brains with natural semantic language capabilities exemplifying the modus operandi for the advancement of understanding, i.e. intelligence, follow

from the fact that the human brain's molecular neural and glial structures correspond ontologically to a yet further progression of the infinite alphabet realized within the DNA / RNA genetic code. Such a progression would permit the human brain by means of NUCRS rewrite mechanisms to input / output natural language, i.e. to hear and to speak, and to process such language semantically, i.e. to proofread it / think, where quantum neural 3D image information processing, akin to that taking place in MRI medical systems worldwide (Schempp (1986, 1992, 1993, 1998), define the beings' sentience.

It also makes clear that the DNA / RNA genetic code is itself both a QCE and a rewrite / further extension of the NUCRS infinite alphabet, realised at the 3D geometric structural molecular level, which we label biological (rather than that of the Standard Model elementary particles which implement the NUCRS's basic nilpotent Dirac quantum computational universal order code), such that the nucleotide base pairings $G=C$ and $A=T$ or $A=U$ realize the NUCRS conserve / proofreading and create operations, where U (RNA) replacing T (DNA) symbolizes the introduction of a new NUCRS symbol. Thus this NUCRS theory of natural process not only specifies a new universal computational nilpotent foundation for physics and biology, but also a wholly computationally consistent one for mathematical natural language, where mathematics, or mathematical language thinking / proofreading, will become potentially realizable in sentient brains, at some level of quantum molecular complexity, 'the neural', which the human brain has now just reached.

This assertion of an alternative computational foundation for mathematics receives confirmation from the general inductive definition of both the NUCRS 'bootstrap' as outlined above and that of John Conway's surreal numbers (discussed in detail in *Zero to Infinity*), where nonstandard analysis over the surreal number fields (Alling, 1988) supports Conway's assertion (1976) 'that mathematics itself founded in (such) an invariant way (as the surreal numbers) would be equivalent to, but would not involve, formalization within some axiomatic theory like Zermelo-Fraenkel (ZF) set theory'. (ZF is currently taken in mathematics as its best foundation, even though it is not an entirely consistent one and can lead to occasional logical paradox.)

In analysis over the surreal number fields, the choice of the next number in the field, its birthorder, follows Conway's simplicity theorem, and it is proven that each such field possesses a unique birthorder field automorphism called its birthordering, and that the simplest unique universal number birthorder field is that of the ordinal numbers. It says each ordinal extends the complexity of all previous ordinals in the simplest possible way, where sums, products, inverses, algebraic extensions, and transcendental extensions are regarded as successively

more complicated concepts. Thus the surreal number fields and the process realization of the NUCRS infinite alphabet as outlined above, share a common general inductive framework / definition / bootstrap, where in the case of the surreal numbers, the void is restricted to the empty set of all numbers ϕ , the label / name for each number is its symbol, and the value of the first number symbol called zero = 0 is defined as $\{\phi|\phi\}$.

This means that the general Dedekind cut $\{ | \}$ used by Conway to generate each surreal number extension as $\{ \{ | \} | \}$ or $\{ | \{ | \} \}$, applying his simplicity criterion, can be viewed as computation, as can the bracket operations, $[a,b] = ab - ba$ of the Lie commutator; $\{a,b\} = ab + ba$, of the Clifford anti-commutator; and $\langle | \rangle$ in the Dirac bra / ket formalism. We can, for example, use $L = i\{H, \}$ or $L = [H,] = H.1 - 1.H$ in mechanics, where H is a Hamiltonian, L is the Liouvillean operator in the Liouville-Von Neumann equation $i\partial/\partial t \rho t = L\rho t$ for the density function ρ , t is time, and $\{ , \}$ is the Poisson Bracket of classical mechanics or $[,]$ the square brackets / commutator in quantum mechanics. This covers quantum dissipative systems, where trajectories are not, in general, operationally meaningful and there may exist an 'internal time' operator T such that $[T, L] = i$ and $[L, t] = 0$. It also illustrates the dependence of calculation by means of any of these bracket operations on the existence of an energy function or Hamiltonian for the physical system in question.

Critically such calculations must possess a canonical labelling if they are to constitute computation and in particular quantum computation (Deutsch 1985). But this is the case in the NUCRS cosmology, where the Pauli exclusion principle, which applies to its fermion states, determines the properties of the novel states of matter in relation to the QCE quantum evolution symbolized by its infinite alphabet. In principle, following Conway, this infinite alphabet symbolizes the quantum universe's unique birthorder field automorphism where each unique fermion's quantum interaction with the rest of the universe, its so called 'vacuum' re-action', must be zero, i.e. is nilpotent. In fact, one such quantum mechanical system with time reversal asymmetry, where all the fermion states lie on a line $\text{spin} = 1/2$, is already known. It concerns the Riemann zeta function $\zeta(x + iy)$, such that all the quantizations of the system correspond to the imaginary parts y of the zeta's nontrivial zeros. These are all hypothesized to lie on the line $x = 1/2$, and thus are also the gauge invariant geometric phases of the system's state vector (which in this case map onto the integers and so are Turing computable).

The significance for AI

Such a brief summary cannot fully explain the full basis for the universal rewrite process, nor the formal structures it develops for quantum mechanics, including the full Hilbert space apparatus or equivalent, and the already second quantized description of the quantum field, and it cannot give extensive detail on the many applications. One of the significant aspects of the process, however, is that quantum mechanics, in this form – the one which we believe to be the most concise and powerful – is *derived entirely from initial concepts of information signal processing*. In effect, this means that some of the arguments which use ‘quantum mechanics’ as a model for nonphysical subjects, such as economics or linguistics, may well be valid because they are using the fundamental structures of information processing which underlie quantum mechanics, rather than because there is any direct connection with the purely physical processes which quantum mechanics normally describes.

However, in connection with the use of quantum mechanics, we should note that, in the system described, it is specifically *nilpotent* (rather than, say, idempotent) quantum mechanics which supplies the semantic code. It is also relativistic and primarily fermionic, rather than bosonic, and the logic is based on the properties of 0 and ∞ , rather than on those of 1 and 0. (The null subspace is not closed but infinitely open.) So, if we want to advance artificial intelligence beyond the level of digital computing, we need to use the only method so far in which the holistic aspect is intrinsic at every step. Nature clearly operates by a recursive mode in which everything has to be decided ‘correctly’ instantaneously and not by an iterative description of a restricted part of the system. Here, it provides the unique birthordering of an infinite series of nilpotent zeros from a universal alphabet of symbols (Marcer and Rowlands, forthcoming), defined by the infinite square roots of -1 (Diaz and Rowlands, 2006). To appreciate this mode of operation, we need an infinite logic rather than a finite one. Using pure mathematics and a Turing machine, we need an alphabet with an infinite number of steps to achieve 0. Using the nilpotent system, we achieve 0 in a finite process, and obtain immediate connection with the rest of the universe.

The nilpotent structure establishes many things which are important to providing information processing on a large scale. In particular it establishes nonequilibrium thermodynamics and the quantum Carnot engine (Scully et al, 2003), because every nilpotent, while being defined to conserve energy, remains a completely open system, and because the unique birthordering of the rewrite system presupposes that a degree of quantum coherence is always present. It also establishes quantum holography, because the terms of the operator alone provide us with complete

information on the system’s amplitude, phase and reference phase. In describing the minimum information required – because we don’t need operator *and* wavefunction, amplitude *and* phase – we also have automatic phase conjugation, because the phase is determined by or determines the amplitude. A consideration of Pauli exclusion and antisymmetric nilpotent wavefunctions, where $\psi_1\psi_2 - \psi_2\psi_1$ reduces to $8i\mathbf{p}_1 \times \mathbf{p}_2$, shows that the universe must be correlated at all times in such a way that each nilpotent wavefunction must instantaneously have a unique phase both in real space and in momentum space, in exactly the manner required by applying the de Broglie pilot wave.

The rewrite structure is, of course, a general description of natural process. It is not confined to systems described directly by quantum physics or pure mathematics. It operates at a hierarchy of levels at which a symbol can be replaced by an entire alphabet, and we find ‘quantum’ characteristics in macroscopic systems (described as ‘phaseonia’ by Scully et al), where a degree of coherence allows us an immediate application of the rewrite process.

As we showed in our paper ‘How Intelligence Evolved?’ (Marcer and Rowlands, 2007), it is finally relevant to those operations of the human brain that we describe as ‘mind’, ‘intelligence’ and ‘consciousness’. It is because the semantic code created by the nilpotent structure is holistic that we make those connections in the brain which create a kind of ‘closure’, placing the object in its context within the whole. The structure says that we must establish finite ‘closure’ of a kind that brings in everything else. We make the phase conjugation, and it is the same in all our mental processes of recognition, even the placing of an object in its position in space. If artificial intelligence is to create the same kind of response in machines that we observe in the human brain, then we must begin by applying the same machine order code to the process that we observe operating in the rest of nature.

Appendix

The Dirac equation in nilpotent form for a free particle would be written:

$$\left(\mp \mathbf{k} \frac{\partial}{\partial t} \mp i\mathbf{i}\nabla + \mathbf{j}m \right) (\pm ikE \pm i\mathbf{p} + \mathbf{j}m) e^{-i(Et - \mathbf{p}\cdot\mathbf{r})} = 0,$$

where the first bracket is a differential operator, represented as a 4-component column vector and the second bracket, together with the exponential phase factor, forms an amplitude, represented as a 4-component column vector. (E , \mathbf{p} , m , t and \mathbf{r} are respectively energy, momentum, mass, time, space and the symbols $1, i, j, k$, $\mathbf{i}, \mathbf{j}, \mathbf{k}$, are used to represent the respective units required by the scalar, pseudo-scalar, quaternion and multivariate

vector groups.) Both of the brackets in the equation are spinors, incorporating the usual four possibilities: fermion / antifermion, spin up / down. The nilpotency comes from the fact that, because the theory is relativistic,

$$(\pm ikE \pm ip + jm)(\pm ikE \pm ip + jm) = 4(E^2 - p^2 - m^2) = 0.$$

This is equivalent to Pauli exclusion $\psi\psi = 0$, or, as $-\psi\psi = 0$, becomes equivalent to the combination state of fermion and vacuum described above. Since E and \mathbf{p} may also represent operators as well as eigenvalues, the same equation can be written in the form:

$$(\pm ikE \pm ip + jm)(\pm ikE \pm ip + jm)e^{-i(Et - \mathbf{p}\cdot\mathbf{r})} = 0.$$

Here, in the first bracket E and \mathbf{p} may respectively represent $i\partial / \partial t$ and $-i\nabla$. However, E and \mathbf{p} may also represent covariant derivatives incorporating interaction potentials, say, $i\partial / \partial t + e\phi + \dots$, and \mathbf{p} could be, say, $-i\nabla + e\mathbf{A} + \dots$. In this case, we adopt the rule that Pauli exclusion still applies and that the new creation operator requires an entirely new, but uniquely defined, phase factor, with a structure which (on differentiation) will produce an amplitude, which squares to zero. In principle, this means that only the creation operator (or first bracket) need be specified to determine the entire behaviour of the fermion and the structure of the rest of the universe which makes this possible. Automatic consequences of this formalism are the characteristic forms of the weak, strong and electric interactions, spin, helicity, structures of bosons and baryons, CPT symmetry, removal of divergences, etc. Calculations also become much easier – for example, the fully relativistic standard ‘hydrogen atom’ calculation takes only six lines.

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additional degree of freedom called the ‘cursor’ to enumerate consecutive logical states, in relation to calculations which ran backward and forward in time as in his classic work on relativistic quantum field theory, so that it was the logical rather than the time order, that was important (*Foundations of Physics*: 16, 6, 507-53). See Peres, A. 1985. Reversible logic and quantum computers. *Physical Review A*: 32, no. 6, 3266-3276, in particular p. 3269.

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