The Quantum Evolution of Matter: The Mechanical Unit of Complexification A Sketch

George L. Farre
Department of Philosophy
Georgetown University
Washington, D.C. USA 20057
farreg@georgetown.edu

ABSTRACT

What follows is a sketch of the *Evolution of Matter*, which began with a so-called Hot Bang estimated to have occurred some 15 giga years ago, and is still going on in the cosmic context. The focus on *matter* is due to a number of factors, the chief one being the observability of its behavior in Space-Time, the sole empirical ground for the representation of nature (Heelan). The evolutionary genesis of natural systems is thus reconstructed on the basis of the *Science of Matter,* and is articulated by means of its language, *quantum mechanics* (QM for short).

Certain assumptions govern the *representation* of the evolutionary process, the principal one being that of the observed *unity of the Cosmos*. The facts that matter is *local* in space-time and that it becomes ever more *complex* as the cosmos expands, result in the diversification of *natural systems*, each type of which is identifiable by the unique specificity of the behavior of its local instances. So a main objective of the scientific theory of evolution is to provide a reasonable account of the diversity of natural systems within the context of the unity of nature.

What natural systems have in common is their *genesis* in the same cosmos, born of a burst of radiant energy of enormous magnitude. This energy is the protean substrate of all that exist, matter being a compacted form of this radiation [Wilczek 1999: 11, 2000: 11]. The materialisation of radiant energy is presently thought to be the effect of vibrations of the primal energy field (Strings, M-branes, etc.), which becomes entangled in complex topologies. The complexity of these entanglements is governed in part by the density of the radiant energy, which decreases progressively as the cosmos expands, the energy filling an increasing volume of space-time where the relevant processes of energy transformation occur.

Energy õ is definable in this context as the dynamical principle of the cosmos. It is desirable to distinguish two main forms of this energy: in the evolutionary context: the original radiant form and the subsequent material form. The former is *non local* (e.g. electromagnetic radiation: radio, television,

radar, etc.), while matter is inherently *local*. The genetic connection between them is governed by the Poincare-Einstein relation õ = mc^2 (from which we get m = õ/c^2). Thus radiant energy may be materialised and matter dematerialised, transformations, which are common occurences in laboratories and in everyday life. The relation between the radiant and material energy forms is apparent in the action of the fields on matter. The science of matter is therefore articulated by QM in terms of the action of õ fields on matter in Space-Time.

The following paper is a sketch of the fundamental process of the complexification of matter in the context of the evolution of the cosmos. It has been published by the Austrian Society for Cybernetic Studies and Artificial Intelligence in March of 2002, and so is already in circulation. It is submitted now because it mirrors a key point of the presentation I gave in October 2001 at the SEE conference in Toronto chaired by Edwina Taborsky.

1 BASIC CONCEPTS

The following statements are taken for granted and will not be argued for here on the grounds of the compelling experimental evidence accumulated in the course of several decades: (a) *evolution* is the defining property of nature, i.e., of the cosmos, and more specifically of the emergence of matter in space/time; (b) the *science of matter* is the functional representation of its evolution in space/time; (c) the *language* used to map the empirical evidence is quantum mechanics, and that used for the modeling of the evolutionary process is group theory, the two related by star algebras (Primas 1990:233; Atmanspacher 1994). The *laws of nature* are ordered patterns of empirical data, while the *laws of science* are designed in part to account for their symmetry properties, which are interpreted as conservation principles. The *scientific theory of evolution* addresses the following issues: (i) the *mechanism* of the evolution of matter*; (ii) the emergence* of natural systems; (iii) their *diversification* in the evolutionary context

In this paper, the approach to the evolution of matter is focused on the dynamical stability of natural systems in their natural environments, these being the contexts where they are observable. The chief merits of this approach are: first, the representation of the assumed unity of nature in a general form accessible to a multidisciplinary audience, the treatment offered here being phenomenological rather than mathematical. Of course, a great deal of information is thereby passed over in silence. To help fill in this gap, at least partially, references to some of the scientific literature are given. These have been chosen for their pertinence and for the reasonable accessibility of their contents by non-specialists. The second merit of this paper is to offer a comprehensive sketch of the dynamical anatomy of the quantum unit of evolution. Its third merit is to identify some consequences that set foundational limits for the science of matter in the evolutionary context.

The presentation is naturally divided into three parts. The first part is designed to *set the stage* for the main theme and thus to provide the basic context in which the title is to be read. The second part is meant to address the *mechanisms of the evolution of matter*, and its complexification. The third part brings out some of the limitations inherent to the science of matter.

2 SETTING THE STAGE

Evolution, the defining characteristic of the cosmos, is a property of matter, its only observable constituent. It began with the so-called Hot Bang and the subsequent expansion of space-time.

The evolution of matter is an inherently dynamical process, its energy, a poorly understood gift of nature sometime referred to as the *Quantum Vacuum* QV, appears in local contexts as a *zero point field.* Two main forms of energy are identifiable in the cosmos: the radiant fields (or *e- fields)*, and their localized form, *matter.* Energy fields are *non-local* and therefore not directly observable, their effects are found only in their action on matter and observed in its behavior, something that should be familiar to any one who uses cell phones, television, etc. or who drops things around. Matter, by contrast, is inherently *local in space/time*. Its behavior under the action of e-fields leaves traces in the domain of observation, i.e., discrete *data*. The ordering of these data is in terms of the actions of e-fields, which is represented by a mathematical structure expressed in a form suitable for the purpose (Dirac 1930, Kirillov 1999, Farre 1998).

Energy, the stuff out of which the dynamical universe is made, is naturally ubiquitous. Therefore, the dynamical elements in terms of which of nature is described are the energy fields whose actions are observable in the behavior of matter.

Two sets of field actions characterise the evolutionary history of the cosmos: the *constructive phase* and the *evolutionary phase* proper.

3 THE CONSTRUCTIVE PHASE

This initial period in the evolutionary history of matter began with a radiating Hot Bang, followed by its expansion and came to a close with the appearance of the first atoms (a period sometimes referred to as the *energy era*). It lasted for about10^5 years, when the energy densities of matter and radiation ceased to equilibrate within the expanding fireball and matter became the dominant form of energy in the cosmos (Chaisson 2001). It is the historical period during which the basic types of matter were constructed, beginning with the most elementary forms and ending with the appearance of the first neutral atoms.

It is also the period during which the effects of energy fields became identifiable in the behavior of the matter, and the first symptoms of their quantal stratification became manifest. This is also the period in the history of the cosmos that was not scientifically accessible until the development of quantum physics.

4 THE EVOLUTIONARY PHASE

This phase began with the separation of the two forms of energy density that marks the end of the constructive phase. It is characterised by the internal complexification of natural systems whose material constituents were all created during the first phase. The gradient of energy density resulting from this separation is the energy context wherein *evolution*, i.e., the complexification of matter, proceeds. The *evolutionary phase* opens up the *matter era* with the progressive dominance of neutral matter and the clearing up of the interstellar heavens. This phase now proceeds with the coming dominance of life over matter and with that of intelligence over life (Chaisson 2001).

The evolution of matter is the effect of transactional energy processes between material systems in a context of decreasing density of radiant energy (Cramer 1986:647). Several mechanisms have been proposed to lead from these transactions directly to the emergence of more complex types of natural systems (Haken 1988, Scott Kelso 1995). Here, I am presenting an archetypal dynamical structure that is sufficiently general to provide a dynamical platform on which the complexification of natural systems in the cosmic context proceeds. It will be called the *Quantal Unit of Evolution* or QUE for short. It has the merit of bringing out important features of evolution, such as the energetic stratification of natural systems and the remarkable properties that depend on it.

5 THE MECHANISM OF EVOLUTION

At the core of QUE are three key dynamical elements: the *superposition* of the energy fields acting on material systems, e.g., particles; their *entanglement* in suitable circumstances, and their *closure* (Farre 2000).

The *entanglement* of energy fields takes many forms, depending on the complexity of the energy context. The result can be seen in the representation of the binding process that constrains material elements. Its most elementary form is the energy transaction between particles in the constructive phase (Cramer 1986). Within an atomic nucleus, it reflects both the nature and the degree of its internal complexity (Williams 1991). The same complexification process is seen in the case of molecular and biosystems (Eigen & Schuster 1972; Haken 1988), and indeed can be found in all unitary natural systems (Farre 1998a).

One of the effects of the entanglement of energy fields is the extraction of energy from the material constituents entrained by the dynamical process. Another is the investment of this energy tax in bringing the entangled fields to *closure*, a process which results in the creation of an *energy boundary* with remarkable properties, among which are the following:

(a) The energy boundary effectively separates the inside of the natural system from its outside, in the sense that it is *opaque* to the transactional processes of energy transformation from either side of it. Its effect is to create two distinct domains not simultaneously observable. The boundary is often referred to in the foundational literature as the *Heisenberg Cut* (HC) (d'Espagnat 1994, Primas 1993, Atmanspacher 1994).

(b) The opacity of the Cut accounts for the fact that the derivation of the representation of the emergent behavior of a natural system from the general principles governing its internal processes is not possible, that the classical dream of reductionism does not abide in the quantal universe.

Indeed, the *opacity* of the energy boundary effectively *shields* the internal regime of the natural system from the fluctuations of its energetic environment, thereby enhancing the dynamical stability on which its unitary character depends. In this manner, the dynamical stability of the system is naturally protected within a specific energy range, whose upper limit is closely related to the energy threshold of its closure.

(c) The density of the radiant energy õr acting on the matter internal to the natural system is higher than that acting on the matter external to it, evolution unfolding down the arrow of time.

These sets of properties resemble the conditions satisfied by a macro system sporting a quantum macro variable, with a wave function and a Schrödinger equation (Greenstein

& Zajong 1997:16), a situation known in observation contexts as *Quantum Macro Behavior* (QMB). The conditions are:

(i) The macroscopic quantum variable of any complex or relatively macroscopic system must be largely decoupled from those of the internal regime (Schweber 1993:34).

(ii) The density of the radiant energy, i.e., the ambient temperature, must be sufficiently low for the eigenvalues of the wave function to be determined experimentally

(iii) The macroscopic variable must be controlled by the internal regime of the micro variables.

In laboratory systems designed to test the predictions QM, these conditions mean that the potential energy of the system must be very low, e.g. $\mathbf{V} \ll S\varphi$. This in turn rules out the possibility of QMB for natural systems in gravitational and electromagnetic fields found on earth. This is the reason why special environments and systems have to be engineered to exhibit the desired quantum behavior (Leggett 1984: 583; Sarma et al 1995: 683).

So stated, the QUE meets all the conditions required for quantum macro behavior. Being a complex natural macrosystem in an evolutionary context, it will be referred to here as a *Quantum Macro System*, (QMS).

According to the principle implicit in the statement of the third and first conditions for QMB, if **P** is the wave function of a macrosystem, then it is *loosely controlled* by the energy transformed by the micro processes, some of which is made available to the whole QMS in the domain of emergence where it can be observed**.** In this case, the control of the macro variable by the micro processes is to be understood as an *enablement* of the former by the latter, and not as a rigid form of control of the type commonly found in engineered systems.

Indeed, one can make the case that the enablement of the macro system by the internal processes is the effect of a new form of causality, *quantum causality*, the energy process that binds the observable system to its dynamical substrate across the energy boundary (Farre 1998a, b). It may be contrasted with the case of superconductivity, which some physicists liken to a QMS. However, in that case the variable **P** is common to all of its individual elements involved in the energy flow (i.e., the Cooper pairs), *externally* entrained in the super conductive stream under the influence of the environment. In this sense, superconductivity may be viewed as a *flockingphase* of electrically charged elements (the Cooper pairs) which, when more generously energized, behave differently. This is shown in tunneling through the energy barrier, where the * function is internal to the fermion pairs (the Josephson effect) rather than external to the bosons involved in superconductivity, the consequence of the two fermions pairing off to make one single particle with zero spin.

6 EXAMPLES OF CONSTRUCTION OF ENERGY SHIELDS

Two brief examples: The first is about the construction of atomic nuclei, using the basic matter created in the constructive phase referred to earlier. First, we should note that there is a difference between a free particle, whose observable behavior reveals its degrees of freedom, and the same particle bound to some system, such as another particle.

Binding is a constraint whose effects are observable in diverse ways. For example, a constrained system behaves differently in the observation plane than it does when it is free. The effect of the constraint is also apparent in the difference between the endogeneous energy naturally stored in the free particle and that available to the bound one. For example, part of the energy stored in the rest mass of the particle is extracted by the binding process, the energy being redistributed for the benefit of the whole nucleus and for its autonomy in its emergent domain. In the case of atoms, the energy stored in the mass of the nucleus is less than the sum of the energies ***B*** stored in the masses of the nucleons prior to their entanglement:

$$M(Z,A)c^2 = ZM_{p}c^2 + (A-Z)M_{n}c^2 - B \quad (1)$$

where **Z** is the number of protons, **A** the atomic number of the nucleus (the total number of nucleons in the nucleus) and

$$B = {}' A \, MAc^2$$

the sum of the masses of the free nucleons. When (1) is divided by the atomic number **A**, it yields the so-called *binding energy per nucleon* **B/A** for that particular nucleus. Ignoring the first few atomic elements, **B/A** remains remarkably constant across the atomic chart, reaching its maximum of **8.7 MeV** for **A = 60** (Nd), and then declining to **7.6 MeV** for Uranium **(A = 92)**. Furthermore, the *density of nuclear matter* is also found to be roughly constant across the periodic table of elements[1]. With the accretion of more nucleons in the nucleus, this formula is modified by the addition of functional terms to account for their influence (Williams 1991).

A remarkable, and indeed stunning example of complexification is offered by the structure of the metabolic cycles. In these cases, the binding of material systems reaches an extremely high degree of complexity unthinkable in non-living matter, with a profusion of functionally complex hypercycles (Eigen 1992).

Therefore, no single formula can represent the nature and structure of the complex processes leading to the closure of the energy fields, save in an archetypal form, like a matrix, of the sort presented here. The evolution of the dynamical anatomy of natural systems, hence that of their emergent behavior, are orchestrated in the quantally syncopated way in which energy alternates between local and non local forms, its most distinctive but poorly understood characteristic.

7 SOME IMPLICATIONS

The chief implications of the theory of evolution have their source in the opacity of the energy boundary, without which there would be no unitary natural systems. One in particular is most potent for the future developments of the science of matter.

The *Heisenberg Cut* is all we can observe of natural systems of any size. The observable domain between the observer and the observed is referred to in the foundational literature as the *epistemic domain*, it is the domain where all the empirical evidence about a natural system is to be found. There is another Cut in whose scope conceptualisation is effected, referred to in the literature as the *Cartesian Cut*. The access to its domain of observation is privileged, and its contents include all we experience as individuals. Both Cuts are energy boundaries in the sense defined earlier, whence their opacity. The Cartesian Cut lies astride our Heisenberg Cut, meaning that it spans both the domain of our experience, which is internal and privileged, and the epistemic domain which, although external to us is accessible to whoever interacts with the natural system, though the experience of it is the observer's own.

Both types of contents are got empirically, and both are mapped by our conceptual instrument, originally our mother's tongue. In particular, it maps the data gathered by observation in either domain, and so we learn on our mother's knees how to make sense of our experience in the same way as we make sense of all accessible data: our one natural language maps both domains of observation.

There is however an important difference between the two. The *ordering of the data*, which is the way conceptualisation is effected, may be communicated to others even when got in the privileged domain of experience and be understood if the language is shared. However, they will not know whether what we said is a credible representation of what we claim to be the case: since the grounds of validation remain inherently private, they can have no access to our data/qualia. By contrast, the data gathered in the epistemic domain are in the public domain, in the sense that anyone can have access them, at least in principle. Although people experience these data privately, the claim that they are so ordered is articulated in a common language, be it natural or quantal. In this case, the grounds of justification for the claim that they are thus and so are accessible to all observers. This is the crucial difference between the two parts of the Cartesian domain: what is got in the epistemic domain is public: therein lies its *criterion of objectivity*, whereas what is got in the privately accessible domain of observation lacks the conditions for objectivity that are inherent in the epistemic domain, such as the disentanglement of the observer, and is as *subjective* as any other experience.

This difference sets the limits of the science of matter. For *science* is a representation of nature as we imagine it to be on the grounds of severely constrained methodological criteria. Science being *about nature*, not about our thoughts of it, the most important methodological criterion is the one that governs the determination of what there is. But this can only be got by direct observation. And observation, which is the result of an interaction, demands both an observer and an observed, the two being distinct. Hence science can only exist where there is an epistemic domain.

There are many types of enquiry where this is not the case. The "know thyself" of the Pythic oracle is not a research program, for there is no objective criterion of correctness. Cognitive science, construed as the science of the mind, is prone to the same failings for the same reason: no epistemic domain. More generally, all attempts to understand a situation of which the observer is an integral part, that is where there is no epistemic domain, lies outside the realm of science as defined above. This holds true of social institutions (economics, the stock market, politics, etc), as well as of the universe construed as an independent objective unit, since we cannot get out of it to observe its Heisenberg Cut.

In some cases, there are alternative strategies centered on the intricacies of the dynamical architecture internal to such systems. These are best used as simulations of expected behavior and can be of value in many situations. However, they are not substitutes for the science of matter in domains where no independent observers can exist, only palliatives that rely on statistical forms of validation. More would be outside the scope of this short paper.

REFERENCES

Atmanspacher, H. & G.J. Dalenoort. Eds. 1994. *Inside versus Outside*. Berlin: Springer Verlag.

Chaisson, E.J. 2001. *Cosmic Evolution: The Rise of Complexity in Nature*. Cambridge, MA.: Harvard University Press.

Cramer, J.G. 1986. The Transactional Interpretation of Quantum Mechanics. *Re. Mod. Phys. 58 :* 647

d'Espagnat, B. 1994. *Veiled Reality: An Analysis of Present-Day Quantum Mechanical Concepts*. New York: Addison-Wesley.

Dirac, P.A.M. 1930. *The Principles of Quantum Mechanics* Oxford: Clarendon Press.

Eigen, M. 1992. *Steps towards Life: A Perspective on Evolution*. Oxford: Oxford University Press.

Eigen, M. and P. Schuster. 1972. *The Hypercyle: A Principle Of Self-Organization* Berlin: Springer Verlag.

Farre, G.L. 1998a Cosmic Evolution: Characteristics and Implications for the Philosophy of Nature. *Acta Polytechnica Scandinavica 91:* 3

Farre, G. L. 1998b The Semantic Filter and the Structure of Observation*, Cybernetics and Systems, Vol I :* 146

Farre, G.L.. 2000. Fundamental and Modal Processes in the Evolution of Natural Systems. *Ann.N.Y. Acad. Sci. Vol. 901*: 237

Farre, G.L. 2002. The Evolution of Matter: the Quantal Unit of Evolution, *AIP* 2002 (in press)

Greenstein G. and A.G. Zajong. 1997. *The Quantum Challenge: Modern Research on the Foundations of Quantum Mechanics*. Boston, MA: Jones & Bartlett

Haken, H. 1988. *Information and Self Organization*. Berlin: Springer Verlag

Heelan, P. Heisenberg and Radical Theoretic Change *Zeitung für allgemeine Wissenchafts-theorie 6:* 113-138

Kirillov, A.A. 1999. Merits and Demerits of the Adjoint Orbit Method *Bull.(N.S.) Am. Math. Soc. 36/4 :* 433-488

Leggett, A. 1984. *Contemporary Physics 25* : 583

Primas, H. 1993. The Cartesian Cut, the Heisenberg Cut and Disentangled Observers. In K.V. Laurikainen and C. Montonen, eds. *Wolfgang Pauli as a Philosopher*. Singapore: World Scientific.

Primas, H. 1990. *Mathematical and Philosophical Questions in the Theory of Open and Macro-scopic Quantum Systems*. In: A. Miller, ed. *Sixty-two Years of Uncertainty*. New York: Plenum.

Sarma, S. Das et al: **Am. J. Phys. 63** (1995), 683

Schweber, S.S. 1993. Physics, Community and the Crisis in Physical Theory *Physics Today Nov. 1993,* 34

Scott Kelso, J.A. 1995. *Dynamic Patterns: The Self Organization of Brain and Behavior*, Cambridge, MA: MIT Press.

Wilczek, F. 1999. Mass without Mass I: Most of Matter *Physics Today November***:** 11

—.2000. Mass without Mass II: The Medium is the Mass- age *Physics Today January***: 11**

—.2000. What is Quantum Theory? *Physics Today June 2000*, 11

Williams, W.S.C. 1991. *Nuclear and Particle Physics*. Oxford, UK: Oxford U.P. 55-61