PROCESS PHYSICS: From QUANTUM FOAM to GENERAL RELATIVITY

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Abstract

Progress in the new information-theoretic process physics[1] is reported in which the link to the phenomenology of general relativity is made. In process physics the fundamental assumption is that reality is to be modelled as self-organising semantic (or internal or relational) information using a self-referentially limited neural network model. Previous progress in process physics included the demonstration that space and quantum physics are emergent and unified, with time a distinct non-geometric process, that quantum phenomena are caused by fractal topological defects embedded in and forming a growing three-dimensional fractal process-space, which is essentially a quantum foam. Other features of the emergent physics were: quantum field theory with emergent flavour and confined colour, limited causality and the Born quantum measurement metarule, inertia, time-dilation effects, gravity and the equivalence principle, a growing universe with a cosmological constant, black holes and event horizons, and the emergence of classicality. Here general relativity and the technical language of general covariance is seen not to be fundamental but a phenomenological construct, arising as an amalgam of two distinct phenomena: the 'gravitational' characteristics of the emergent quantum foam for which 'matter' acts as a sink, and the classical 'spacetime' measurement protocol, but with the later violated by quantum measurement processes. Quantum gravity, as manifested in the emergent Quantum Homotopic Field Theory of the process-space or quantum foam, is logically prior to the emergence of the general relativity phenomenology, and cannot be derived from it.

Key words: process physics, neural network, semantic information, self-referential
noise, process-time, quantum foam, general relativity, quantum gravity.

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[1]**Process Physics** Web Page: http://www.socpes.flinders.edu.au/people/rcahill/processphysics.html

1 Introduction

Process Physics [1, 2, 3, 4, 5, 6] is a radical information-theoretic modelling of reality which arose from analysis of various extant limitations; from the limitations of formal information systems discovered by Gödel, Turing and Chaitin, from the limitations of the geometric modelling of time in the models constructed by Galileo, Newton and Einstein, and by the limitations of the quantum theory and its failure to account for the measurement process. As is usual within physics these limitations were obscured by various metarules and metaphysical stories that have become treasured folklore, particularly the curved spacetime construct which is the particular subject of this work.

In process physics the fundamental assumption is that reality is to be modelled as self-organising semantic information, that is, information that is 'internally' meaningful, using a self-referentially limited neural network model. Such a system has no *a priori* objects or laws, and is evolved using a bootstrap system, so that it is the system itself that 'internally' creates patterns of relationships and their dominant modes of behaviour, and all (sub)systems are fractal in character, that is, relationships within relationships, and so on *ad infinitum*. In this way all emergent phenomena are unified, and it is this key feature that has resulted in an understanding and linking, for the first time, of various phenomena. A key feature of this process-physics is that this fracticality is associated with self-organising criticality.

Previous progress in process physics included the demonstration that space and quantum physics are emergent and unified, with time a distinct non-geometric process, that quantum phenomena are caused by fractal topological defects embedded in and forming a growing three-dimensional fractal process-space, which is essentially a quantum foam. Other features of the emergent physics were quantum field theory with emergent flavour and confined colour, limited causality and the Born quantum measurement metarule, inertia, time-dilation effects, gravity and the equivalence principle, a growing universe with a cosmological constant, black holes and event horizons, and the emergence of classicality.

As noted in [1] process physics results in the emergence of a quantum-foam explanation for space, and for which quantum 'matter' effectively acts as a sink. This provides an explanation for the logical necessity of the phenomenon of gravity. Here, as well as updating previous results, the major new development is the derivation of General Relativity, along with its technical language of General Covariance. General Relativity, and its key concept of *spacetime*, is seen not to be fundamental but rather a subtle phenomenological construct, arising as an amalgam of two distinct phenomena: the 'gravitational' characteristics of the emergent quantum foam, and the classical 'spacetime' measurement protocol, but with the later violated by quantum measurements. As we shall see the 'gravitational' effects of the quantum foam causes observers, using their measurement protocol, to create a pseudo-Riemannian manifold history book (the spacetime construct) of classical events, but it is entirely erroneous to think that the curvature of this construct is the *cause* of gravity, or in any way determines how matter moves.

A key long-standing goal of physics has been the unification of gravity and the quantum theory. This unification could not be achieved within the old *non-process physics*, but has now been achieved with the new *process physics*, but as expected only at the expense of atleast one of the combatant theories, and it is general relativity that must concede defeat. However the quantum theory has a shallow victory as it in turn is an emergent phenomenon, arising from the non-geometric and non-quantum self-referentially-limited neural network model which implements the semantic information approach to comprehending reality. Nevertheless it must be emphasised that the conventional non-process physics models will continue to be useful techniques in analysing problems, and in particular this applies to general relativity and the standard quantum theory. What has been achieved in

process physics is the explanation of why reality must be so, and why the modes of behaviour are encodeable in the syntax of the non-process physics. This older mode of dealing with reality will continue to be used because for many problems it is eminently practical. It will require the continued use of various metarules to overcome its limitations, but we now have an explanation for them as well.

Process Physics shows that there is a Quantum Gravity, but it is unrelated to General Relativity and General Covariance, and essentially describes the emergent quantum phenomena of the process-space or quantum foam, and its response to quantum 'matter'. This Quantum Gravity is manifested in the emergent Quantum Homotopic Field Theory for the process-space or quantum foam, and is logically prior to the emergence of the general relativity phenomenology, and cannot be derived from it. It should be noted that as the general relativity syntax is, in part, the result of the 'classical' spacetime measurement protocol used by observers, if one were considering the 'quantising' of the classical phenomena of general relativity, and 'quantisation' is always a dubious enterprise at best, then one would sensibly remove the observer protocol effects before undertaking such a task. Unfortunately the conventional orthodoxy has resulted in the total obscurification of this insight.

The ongoing failure of physics to fully match all the aspects of the phenomena of time, apart from that of order, arises because physics has always used non-process models, as is the nature of formal or syntactical systems. Such systems do not require any notion of process - they are entirely structural and static. The new process physics overcomes these deficiencies by using a non-geometric process model for time, but process physics also argues for the importance of relational or semantic information in modelling reality. Semantic information refers to the notion that reality is a purely informational system where the information is internally meaningful. Hence the information is 'content addressable', rather than is the case in the usual syntactical information modelling where the information is represented by symbols. This symbolic or syntactical mode is only applicable to higher level phenomenological descriptions, and for that reason was discovered first.

A pure semantic information system must be formed by a subtle bootstrap process. The mathematical model for this has the form of a stochastic neural network (SNN) for the simple reason that neural networks are well known for their pattern or non-symbolic information processing abilities [7]. The stochastic behaviour is related to the limitations of syntactical systems discovered by Gödel [8] and more recently extended by Chaitin [9, 10, 11], but also results in the neural network being innovative in that it creates its own patterns. The neural network is self-referential, and the stochastic input, known as self-referential noise, acts both to limit the depth of the self-referencing and also to generate potential order.

This work reports on the ongoing development of process physics beginning with a discussion of the comparison of the syntactical and the new semantic information system and their connections with Gödel's incompleteness theorem. Later sections describe the emergent unification of gravitational and quantum phenomena, amounting to a quantum theory of gravity. In particular the derivation of general relativity and its downgrading to a phenomenological tool is presented.

2   Syntactical and Semantic Information Systems

In modelling reality with formal or syntactical information systems physicists assume that the full behaviour of a physical system can be compressed into axioms and rules for the manipulation of symbols. However Gödel discovered that self-referential syntactical systems (and these include basic mathematics) have fundamental limitations which amount to the realisation that not all truths can be compressed into an axiomatic structure, that formal systems are much weaker than

previously supposed. In physics such systems have always been used in conjunction with metarules and metaphysical assertions, all being 'outside' the formal system and designed to overcome the limitations of the syntax. Fig.1 depicts the current understanding of self-referential syntactical systems. Here the key feature is the Gödel boundary demarcating the provable from the unprovable truths of some system. Chaitin, using Algorithmic Information Theory, has demonstrated that in mathematics the unprovable truths are essentially random in character. This, however, is a structural randomness in the sense that the individual truths do not have any structure to them which could be exploited to condense them down to or be encoded in axioms. This is unlike random physical events which occur in time. Of course syntactical systems are based on the syntax of symbols and this is essentially non-process or non-timelike.
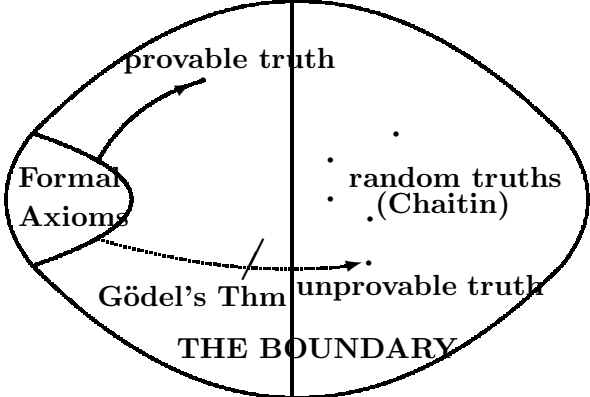

Figure 1: Graphical depiction of the 'logic space' of a self-referential syntactical information system, showing the formal system consisting of symbols and rules, and an example of one theorem (a provable truth). Also shown are unprovable truths which in general are random (or unstructured) in character, following the work of Chaitin. The Gödelian boundary is the demarcation between provable and unprovable truths.

There is an analogy between the structure of self-referential syntactical information systems and the present structure of quantum theory, as depicted in Fig.2.
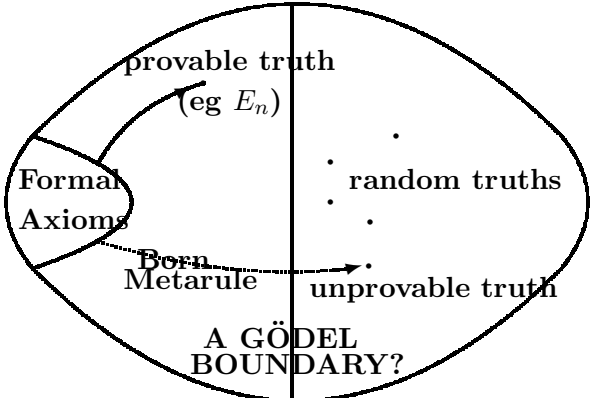

Figure 2: Graphical depiction of the syntactical form of conventional quantum theory. The Born measurement metarule appears to bridge a Gödel-like boundary.

There the formal and hence non-process mathematical structure is capable of producing many provable truths, such as the energy levels of the hydrogen atom, and these are also true in the sense that they agree with reality. But from the beginning of quantum theory the Born measurement metarule was introduced to relate this non-process modelling to the actual randomness of quantum

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measurement events. The individuality of such random events is not a part of the formal structure of quantum theory. Of course it is well known that the non-process or structural aspects of the probability metarule are consistent with the mathematical formalism, in the form of the usual 'conservation of probability' equation and the like. Further, the quantum theory has always been subject to various metaphysical interpretations, although these have never played a key role for practitioners of the theory. This all suggests that perhaps the Born metarule is bridging a Gödel-type boundary, that there is a bigger system required to fully model quantum aspects of reality, and that the boundary is evidence of self-referencing in that system.

Together the successes and failures of physics suggest that a generalisation of the traditional use of syntactical information theory is required to model reality, and that this has now been identified as a semantic information system which has the form of a stochastic neural network.
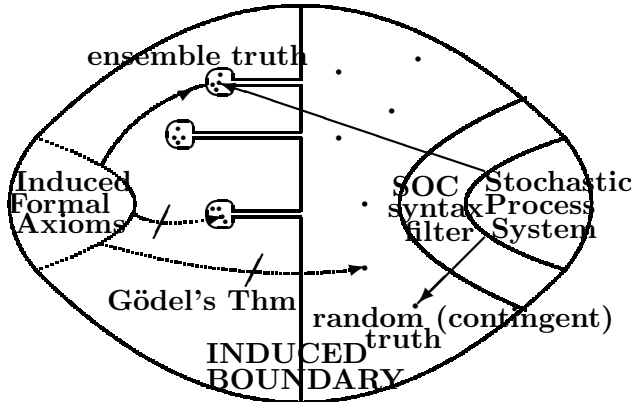

Figure 3: Graphical depiction of the bootstrapping of and the emergent structure of a self-organising pure semantic information system. As a high level effect we see the emergence of an induced formal system, corresponding to the current standard syntactical modelling of reality. There is an emergent Gödel-type boundary which represents the inaccessibility of the random or contingent truths from the induced formal or syntactical system. A process of self-organised criticality (SOC) filters out the seeding or bootstrap syntax.

Fig.3 shows a graphical depiction of the bootstrapping of a pure semantic information system, showing the stochastic neural network-like process system from which the semantic system is seeded or bootstrapped. Via a Self-Organised Criticality Filter (SOCF) this seeding system is removed or hidden. From the process system, driven by Self-Referential Noise (SRN), there are emergent truths, some of which are generically true (ensemble truths) while others are purely contingent. The ensemble truths are also reachable from the Induced Formal System as theorems, but from which, because of the non-process nature of the induced formal system, the contingent truths cannot be reached. In this manner there arises a Gödel-type boundary. The existence of the latter leads to induced metarules that enhance the induced formal system, if that is to be used solely in higher order phenomenology.

Western science and philosophy has always been dominated by non-process thought. This 'historical record' or *being* model of reality has been with us since Parmenides, and his student Zeno, of Elea, and is known as the Eleatic model (c500 BCE). However, nevertheless, and for the dubious reason of generating support for his supervisors *being* model of reality, Zeno gave us the first insights into the inherent problems of comprehending motion, a problem long forgotten by conventional non-process physics, but finally explained by process physics. The *becoming* or *processing* model of reality dates back to Heraclitus of Ephesus (540-480 BCE) who argued that common sense is mistaken in thinking that the world consists of stable things; rather the world is in a state of flux. The appearances of 'things' depend upon this flux for their continuity and

identity. What needs to be explained, Heraclitus argued, is not change, but the appearance of stability. With process physics western science and philosophy is now able to move beyond the moribund non-process mindset. While it was the work of Gödel who demonstrated beyond any doubt that the non-process system of thought had fundamental limitations; implicit in his work is that the whole reductionist mindset that goes back to Thales of Miletus could not offer, in the end, an effective account of reality. However the notion that there were limits to syntactical or symbolic encoding is actually very old. Priest [12] has given an account of that history. However in the East the Buddhists in particular were amazingly advanced in their analysis and comprehension of reality. Stcherbatsky [13], writing about the extraordinary achievements of Buddhist logic in the C6 and C7th CE, noted that;

> *Reality according to Buddhists is kinetic, not static, but logic, on the other hand, imagines a reality stabilized in concepts and names. The ultimate aim of Buddhist logic is to explain the relation between a moving reality and the static constructions of logic.*

In the West the process system approach to reality was developed, much later, by such *process philosophers* as Peirce, James, Bergson and Whitehead to name a few, although their achievements were very limited and substantially flawed, limited as they were by the physical phenomena known to them. A collection of their writings is available in [14]. Perhaps a quote from Charles Peirce [14], writing in 1891, gives the sense of their thinking;

> *The one intelligible theory of the universe is that of objective idealism, that matter is effete mind, inveterate habits becoming physical laws. But before this can be accepted it must show itself capable of explaining the tridimensionalty of space, the laws of motion, and the general characteristics of the universe, with mathematical clearness and precision; for no less should be demanded of every philosophy.*

With process physics we have almost achieved this end, and Wheeler has already expressed this notion of *inveterate habits* as "law without law" [16]. As the astute reader will note the self-referentially limited neural network model, that underpins process physics, is remarkably akin to Peirce's *effete mind*. But it is the limitations of syntax, and the need for intrinsic or semantic information 'within' reality and at all levels, that reality is not imposed, that drives us to this approach. Einstein, the modern day eleatic thinker, realised all too well the limitations of non-process thinking, but was unable to move out of the non-process realm that the West had created for itself, for according to Carnap [15];

> *Once Einstein said that the problem of the Now worried him seriously. He explained that the experience of the Now means something special for man, something essentially different from the past and the future, but that this important difference does not and cannot occur within physics. That this experience cannot be grasped by science seems to him a matter of painful but inevitable resignation. I remarked that all that occurs objectively can be described in science: on the one hand the temporal sequence of events is described in physics; and, on the other hand, the peculiarities of man's experiences with respect to time, including his different attitude toward past, present and future, can be described and (in principle) explained in psychology. But Einstein thought that scientific descriptions cannot possibly satisfy our human needs; that there is something essential about the Now which is just outside of the realm of science.*

3 Self-Referentially Limited Neural Networks

Here we briefly describe a model for a self-referentially limited neural network and in the following section we describe how such a network results in emergent quantum behaviour, and which, increasingly, appears to be a unification of space and quantum phenomena. Process physics is a semantic information system and is devoid of *a priori* objects and their laws and so it requires a subtle bootstrap mechanism to set it up. We use a stochastic neural network, Fig.4a, having the structure of real-number valued connections or relational information strengths B_{ij} (considered as forming a square matrix) between pairs of nodes or pseudo-objects i and j. In standard neural networks [7] the network information resides in both link and node variables, with the semantic information residing in attractors of the iterative network. Such systems are also not pure in that there is an assumed underlying and manifest *a priori* structure.

The nodes and their link variables will be revealed to be themselves sub-networks of informational relations. To avoid explicit self-connections $B_{ii} \neq 0$, which are a part of the sub-network content of i, we use antisymmetry $B_{ij} = -B_{ji}$ to conveniently ensure that $B_{ii} = 0$, see Fig.4b.

At this stage we are using a syntactical system with symbols B_{ij} and, later, rules for the changes in the values of these variables. This system is the syntactical seed for the pure semantic system. Then to ensure that the nodes and links are not remnant *a priori* objects the system must generate strongly linked nodes (in the sense that the B_{ij} for these nodes are much larger than the B_{ij} values for non- or weakly-linked nodes) forming a fractal network; then self-consistently the start-up nodes and links may themselves be considered as mere names for sub-networks of relations. For a successful suppression the scheme must display self-organised criticality (SOC) [17] which acts as a filter for the start-up syntax. The designation 'pure' refers to the notion that all seeding syntax has been removed. SOC is the process where the emergent behaviour displays universal criticality in that the behaviour is independent of the individual start-up syntax; such a start-up syntax then has no ontological significance.

To generate a fractal structure we must use a non-linear iterative system for the B_{ij} values. These iterations amount to the necessity to introduce a time-like process. Any system possessing *a priori* 'objects' can never be fundamental as the explanation of such objects must be outside the system. Hence in process physics the absence of intrinsic undefined objects is linked with the phenomena of time, involving as it does an ordering of 'states', the present moment effect, and the distinction between past and present. Conversely in non-process physics the presence of *a priori* objects is related to the use of the non-process geometrical model of time, with this modelling and its geometrical-time metarule being an approximate emergent description from process-time. In this way process physics arrives at a new modelling of time, *process time*, which is much more complex than that introduced by Galileo, developed by Newton, and reaching its high point with Einstein's spacetime geometrical model. Unlike these geometrical models process-time does model the *Now* effect. Process physics also shows that time cannot be modelled by any other structure, other than a time-like process, here an iterative scheme. There is nothing *like* time available for its modelling. The near obsession of theoretical physicists with the geometrical modelling of time, and its accompanying notion of *determinism*, has done much to retard the development of physics. The success of process physics implies that time along with self-referencing is in some sense prior to the other phenomena, and certainly prior to space, as will be seen in sect.7 within the discussion of a multi-component universe.

The stochastic neural network so far has been realised with one particular scheme involving a stochastic non-linear matrix iteration, see (1). The matrix inversion B^{-1} then models self-referencing in that it requires all elements of B to compute any one element of B^{-1}. As well there
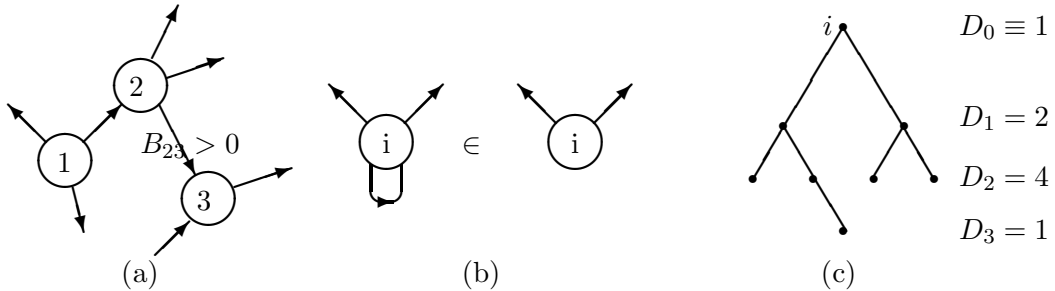
Figure 4: (a) Graphical depiction of the neural network with links $B_{ij} \in \mathcal{R}$ between nodes or pseudo-objects. Arrows indicate sign of B_{ij}. (b) Self-links are internal to a node, so $B_{ii} = 0$. (c) An $N = 8$ spanning tree for a random graph (not shown) with $L = 3$. The distance distribution D_k is indicated for node i.

is the additive SRN w_{ij} which limits the self-referential information but, significantly, also acts in such a way that the network is innovative in the sense of generating semantic information, that is information which is internally meaningful. The emergent behaviour is believed to be completely generic in that it is not suggested that reality is a computation, rather it appears that reality has the form of an self-referential order-disorder information system. It is important to note that process physics is a non-reductionist modelling of reality; the basic iterator (1) is premised on the general assumption that reality is sufficiently complex that self-referencing occurs, and that this has limitations. Eqn.(1) is then a minimal bootstrapping implementation of these notions. At higher emergent levels this self-referencing manifests itself as *interactions* between emergent patterns, but other novel effects may also arise.

To be a successful contender for the Theory of Everything (TOE) process physics must ultimately prove the uniqueness conjecture: that the characteristics (but not the contingent details) of the pure semantic information system are unique. This would involve demonstrating both the effectiveness of the SOC filter and the robustness of the emergent phenomenology, and the complete agreement of the later with observation.

The stochastic neural network is modelled by the iterative process[2]

$$B_{ij} \to B_{ij} - \alpha(B + B^{-1})_{ij} + w_{ij}, \quad i, j = 1, 2, ..., 2M; M \to \infty, \tag{1}$$

where $w_{ij} = -w_{ji}$ are independent random variables for each ij pair and for each iteration and

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[2]While not directly relevant it may be helpful to the reader to outline the line of thought that led to (1), arising as it did from the quantum field theory frontier of quark physics. A highly effective approximation to QCD was developed that made extensive use of bilocal fields and the functional integral calculus (FIC), see [29] for reviews of this Global Colour Model (GCM). The core effect in the GCM, which uses the Euclidean metric, but with analytic continuation back to the Minkowski metric, is the constituent quark effect, which is a non-linear equation for those non-zero bilocal fields about which the induced effective action for hadronic fields is to be expanded (the Dyson-Schwinger equation for the bilocal fields effective action). If we strip away the spacetime and quantum number indices from that equation, we arrive at (1), but without the SRN term, as done in R.T. Cahill and C.M. Klinger, *Pregeometric Model of the Spacetime Phenomenology*, Phys. Lett. A**223**(1996)313. But as is apparent there it was impossible to recover the quantum phenomena. However if in the GCM the constituent quark equations are extended by incorporating a bilocal stochastic term and so making the equation an iterative one, then the iterations of this generalised equation generate not only the constituent quark effect but all the emergent hadronic field phenomenology. This is because of the mysterious stochastic quantisation procedure discovered by G. Parisi and Y. Wu, *Scientia Sinica* **24**, 483(1981). This stochastic noise was interpreted as the new intrinsic Self-Referential Noise in [2], when the connection with the work of Gödel and Chaitin became apparent, and we finally arrive at (1). Hence beneath quantum field theory there is evidence of a self-referential stochastic neural network, and its interpretation as a semantic information system. Only by discarding the spacetime background of QFT do we discover the necessity for time, space, and the quantum.

chosen from some probability distribution. Here α is a parameter the precise value of which should not be critical but which influences the self-organisational process. We start the iterator at $B \approx 0$, representing the absence of information. With the noise absent the iterator behaves in a deterministic and reversible manner, giving a condensate-like system, given by the matrix

$$B = MDM^{-1}; \quad D = \begin{pmatrix} 0 & +b_1 & 0 & 0 \\ -b_1 & 0 & 0 & 0 \\ 0 & 0 & 0 & +b_2 \\ 0 & 0 & -b_2 & 0 \\ & & & & \cdot \\ & & & & & \cdot \end{pmatrix}, \quad b_1, b_2, ... \geq 0, \quad (2)$$

where M is a real orthogonal matrix determined uniquely by the start-up B, and each b_i evolves according to the iterator $b_i \rightarrow b_i - \alpha(b_i - b_i^{-1})$, but it does serve as the non-metriciseable background for the muti-world universe discussed later. In the presence of the noise the iterator process is non-reversible and non-deterministic. It is also manifestly non-geometric and non-quantum, and so does not assume any of the standard features of syntax based physics models. The dominant mode is the formation of an apparently randomised background (in B_{ij}) but, however, it also manifests a self-organising process which results in a growing three-dimensional fractal process-space that competes with this random background - the formation of a 'bootstrapped universe'. Here we report on the current status of ongoing work to extract the nature of this 'universe'.

The emergence of order in this system might appear to violate expectations regarding the 2nd Law of Thermodynamics; however because of the SRN the system behaves as an open system and the growth of order arises from the self-referencing term, B^{-1} in (1), selecting certain implicit order in the SRN. Hence the SRN acts as a source of negentropy[3]

This growing three-dimensional fractal process-space is an example of a Prigogine far-from-equilibrium dissipative structure [19] driven by the SRN. From each iteration the noise term will additively introduce rare large value w_{ij}. These w_{ij}, which define sets of strongly linked nodes, will persist through more iterations than smaller valued w_{ij} and, as well, they become further linked by the iterator to form a three-dimensional process-space with embedded topological defects. In this way the stochastic neural-network creates stable strange attractors and as well determines their interaction properties. This information is all internal to the system; it is the semantic information within the network.

To see the nature of this internally generated information consider a node i involved in one such large w_{ij}; it will be connected via other large w_{ik} to a number of other nodes and so on, and this whole set of connected nodes forms a connected random graph unit which we call a gebit as it acts as a small piece or bit of geometry formed from random information links and from which the process-space is self-assembled. The gebits compete for new links and undergo mutations. Indeed, as will become clear, process physics is remarkably analogous in its operation to biological systems. The reason for this is becoming clear: both reality and subsystems of reality must use semantic information processing to maintain existence, and symbol manipulating systems are totally unsuited to this need, and in fact totally contrived.

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[3]The term *negentropy* was introduced by E. Schrödinger [18] in 1945, and since then there has been ongoing discussion of its meaning. In process physics it manifests as the SRN.
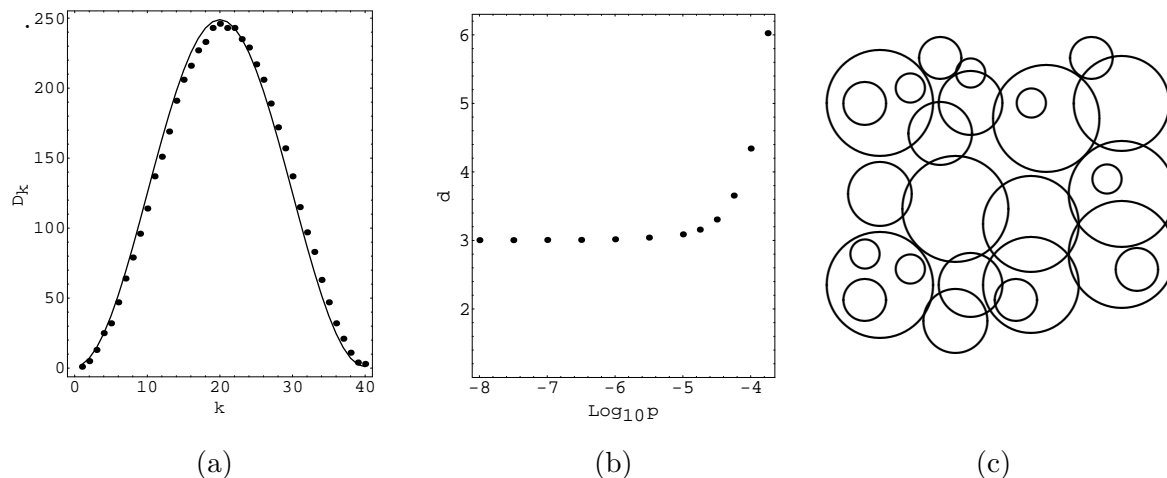
Figure 5: (a) Points show the D_k set and $L = 40$ value found by numerically maximising $\mathcal{P}[D, L, N]$ for $\text{Log}_{10} p = -6$ for fixed $N = 5000$. Curve shows $D_k \propto \sin^{d-1}(\frac{\pi k}{L})$ with best fit $d = 3.16$ and $L = 40$, showing excellent agreement, and indicating embeddability in an S^3 with some topological defects. (b) Dimensionality d of the gebits as a function of the probability p. (c) Graphical depiction of the 'process space' at one stage of the iterative process-time showing a quantum-foam structure formed from embeddings and linkings of gebits. The linkage connections have the distribution of a 3D space, but the individual gebit components are closed compact spaces and cannot be embedded in a 3D background space. So the drawing is only suggestive. Nevertheless this figure indicates that process physics generates a cellular information system, where the behaviour is determined at all levels by internal information.

To analyse the connectivity of such gebits assume for simplicity that the large w_{ij} arise with fixed but very small probability p, then the geometry of the gebits is revealed by studying the probability distribution for the structure of the random graph units or gebits minimal spanning trees with D_k nodes at k links from node i ($D_0 \equiv 1$), see Fig.4c, this is given by [20]

$$\mathcal{P}[D, L, N] \propto \frac{p^{D_1}}{D_1! D_2! .... D_L!} \prod_{i=1}^{L-1} (q^{\sum_{j=0}^{i-1} D_j})^{D_{i+1}} (1 - q^{D_i})^{D_{i+1}}, \qquad (3)$$

where $q = 1 - p$, N is the total number of nodes in the gebit and L is the maximum depth from node i. To find the most likely connection pattern we numerically maximise $\mathcal{P}[D, L, N]$ for fixed N with respect to L and the D_k. The resulting L and $\{D_1, D_2, ..., D_L\}$ fit very closely to the form $D_k \propto \sin^{d-1}(\pi k/L)$; see Fig.5a for $N = 5000$ and $\text{Log}_{10} p = -6$. The resultant d values for a range of $\text{Log}_{10} p$ and $N = 5000$ are shown in Fig.5b.

This shows, for p below a critical value, that $d = 3$, indicating that the connected nodes have a natural embedding in a 3D hypersphere S^3; call this a base gebit. Above that value of p, the increasing value of d indicates the presence of extra links that, while some conform with the embeddability, are in the main defects with respect to the geometry of the S^3. These extra links act as topological defects. By themselves these extra links will have the connectivity and embedding geometry of numbers of gebits, but these gebits have a 'fuzzy' embedding in the base gebit. This is an indication of fuzzy homotopies (a homotopy is, put simply, an embedding of one space into another). Here we see the emergence of geometry, not only of space but the internal symmetry spaces of quantum fields.

The base gebits $g_1, g_2, ...$ arising from the SRN together with their embedded topological defects have another remarkable property: they are 'sticky' with respect to the iterator. Consider the larger valued B_{ij} within a given gebit g, they form tree graphs and most tree-graph adjacency matrices

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are singular ($\det(g_{tree}) = 0$). However the presence of other smaller valued B_{ij} and the general background noise ensures that $\det(g)$ is small but not exactly zero. Then the B matrix has an inverse with large components that act to cross-link the new and existing gebits. This cross-linking is itself random, due to the presence of background noise, and the above analysis may again be used and we would conclude that the base gebits themselves are formed into a 3D hypersphere with embedded topological defects. The nature of the resulting 3D process-space is suggestively indicated in Fig.5c, and behaves essentially as a quantum foam [21].

Over ongoing iterations the existing gebits become cross-linked and eventually lose their ability to undergo further linking; they lose their 'stickiness' and decay. The value of the parameter α in (1) must be small enough that the 'stickiness' persists over many iterations, that is, it is not quenched too quickly, otherwise the emergent network will not grow. Hence the emergent space is 3D but is continually undergoing replacement of its component gebits; it is an informational process-space, in sharp distinction to the non-process continuum geometrical spaces that have played a dominant role in modelling physical space. If the noise is 'turned off' then this emergent dissipative space will decay and cease to exist. We thus see that the nature of space is deeply related to the logic of the limitations of logic, as implemented here as a self-referentially limited neural network.

4   Modelling Gebits and their Topological Defects

We need to extract convenient but approximate syntactical descriptions of the semantic information in the network, and these will have the form of a sequence of mathematical constructions, the first being the Quantum Homotopic Field Theory. Importantly they must all retain explicit manifestations of the SRN. To this end first consider the special case of the iterator when the SRN is frozen at a particular w, that is we consider iterations with an artificially fixed SRN term. Then the iterator is equivalent to the minimisation of an 'energy' expression (remember that B and w are antisymmetric)

$$E[B; w] = -\frac{\alpha}{2}\mathrm{Tr}[B^2] - \alpha\mathrm{TrLn}[B] + \mathrm{Tr}[wB]. \tag{4}$$

Note that for disconnected gebits g_1 and g_2 this energy is additive, $E[g_1 \oplus g_2] = E[g_1] + E[g_2]$. Now suppose the fixed w has the form of a gebit approximating an S^3 network with one embedded topological defect which is itself an S^3 network, for simplicity. So we are dissecting the gebit into base gebit, defect gebit and linkings or embeddings between the two. We also ignore the rest of the network, which is permissible if our gebit is disconnected from it. Now if $\det(w)$ is not small, then this gebit is non-sticky, and for small α, the iterator converges to $B \approx \frac{1}{\alpha}w$, namely an enhancement only of the gebit. However because the gebits are rare constructs they tend to be composed of larger w_{ij} forming tree structures, linked by smaller valued w_{ij}. The tree components make $\det(w)$ smaller, and then the inverse B^{-1} is activated and generates new links. Hence, in particular, the topological defect relaxes, according to the 'energy' measure, with respect to the base gebit. This relaxation is an example of a 'non-linear elastic' process [22]. The above gebit has the form of a mapping $\pi : S \to \Sigma$ from a base space to a target space. Manton [23, 24, 25] has constructed the continuum form for the 'elastic energy' of such an embedding and for $\pi : S^3 \to S^3$ it is the Skyrme energy

$$E[U] = \int \left[-\frac{1}{2}\mathrm{Tr}(\partial_i U U^{-1}\partial_i U U^{-1}) - \frac{1}{16}\mathrm{Tr}[\partial_i U U^{-1}, \partial_i U U^{-1}]^2 \right], \tag{5}$$

where $U(x)$ is an element of $SU(2)$. Via the parametrisation $U(x) = \sigma(x) + i\vec{\pi}(x).\vec{\tau}$, where the τ_i are Pauli matrices, we have $\sigma(x)^2 + \vec{\pi}(x)^2 = 1$, which parametrises an S^3 as a unit hypersphere embedded in E^4 (which has no ontological significance, of course). Non-trivial minima of $E[U]$

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are known as Skyrmions (a form of topological soliton), and have $Z = \pm 1, \pm 2, ...$, where Z is the winding number of the map,

$$Z = \frac{1}{24\pi^2} \int \sum \epsilon_{ijk} \text{Tr}(\partial_i U U^{-1} \partial_j U U^{-1} \partial_k U U^{-1}). \tag{6}$$

The first key to extracting emergent phenomena from the stochastic neural network is the validity of this continuum analogue, namely that $E[B; w]$ and $E[U]$ are describing essentially the same 'energy' reduction process. This should be amenable to detailed analysis.

This 'frozen' SRN analysis of course does not match the time-evolution of the full iterator (1), for this displays a much richer collection of processes. With ongoing new noise in each iteration and the saturation of the linkage possibilities of the gebits emerging from this noise, there arises a process of ongoing birth, linkaging and then decay of most patterns. The task is then to identify those particular patterns that survive this flux, even though all components of these patterns eventually disappear, and to attempt a description of their modes of behaviour. This brings out the very biological nature of the information processing in the SNN, and which appears to be characteristic of a 'pure' semantic information system. Hence the emergent 'laws of physics' are the habitual habits of this system, and it appears that they maybe identified. However there is no encoding mechanism for these 'laws', they are continually manifested; there is no *cosmic code*. In contrast living or biological systems could be defined as those emergent patterns which discovered how to encode their 'laws', in a syntactical *genetic code*. Nevertheless such biological systems make extensive use of semantic information at all levels, as their genetic code is expressed in the phenotype.

In general each gebit, as it emerges from the SRN, has active nodes and embedded topological defects, again with active nodes. Further there will be defects embedded in the defects and so on, and so gebits begin to have the appearance of a fractal defect structure, and all the defects having various classifications and associated winding numbers. The energy analogy above suggests that defects with opposite winding numbers at the same fractal depth may annihilate by drifting together and merging. Furthermore the embedding of the defects is unlikely to be 'classical', in the sense of being described by a mapping $\pi(x)$, but rather would be fuzzy, i.e described by some functional, $F[\pi]$, which would correspond to a classical embedding only if F has a very sharp supremum at one particular $\pi = \pi_{cl}$. As well these gebits are undergoing linking because their active nodes (see [3] for more discussion) activate the B^{-1} new-links process between them, and so by analogy the gebits themselves form larger structures with embedded fuzzy topological defects. This emergent behaviour is suggestive of a quantum space foam, but one containing topological defects which will be preserved by the system, unless annihilation events occur. If these topological defects are sufficiently rich in fractal structure as to be preserved, then their initial formation would have occurred as the process-space relaxed out of its initial, essentially random form. This phase would correspond to the early stages of the Big-Bang. Once the topological defects are trapped in the process-space they are doomed to meander through that space by essentially self-replicating, i.e. continually having their components die away and be replaced by similar components. These residual topological defects are what we call matter. The behaviour of both the process-space and its defects is clearly determined by the same network processes; we have an essential unification of space and matter phenomena. This emergent quantum foam-like behaviour suggests that the full generic description of the network behaviour is via the Quantum Homotopic Field Theory (QHFT) of the next section. We also see that cellular structures are a general feature of semantic information systems, with the information necessarily distributed.

5   Modelling the Emergent Quantum Foam

To construct this QHFT we introduce an appropriate configuration space, namely all the possible homotopic mappings $\pi_{\alpha\beta} : S_\beta \to S_\alpha$, where the $S_1, S_2, ..$, describing 'clean' or topological-defect free gebits, are compact spaces of various types. Then QHFT has the form of an iterative functional Schrödinger equation for the discrete time-evolution of a wave-functional $\Psi[...., \pi_{\alpha\beta}, ...; t]$

$$\Psi[...., \pi_{\alpha\beta}, ...; t + \Delta t] = \Psi[...., \pi_{\alpha\beta}, ...; t] - iH\Psi[...., \pi_{\alpha\beta}, ...; t]\Delta t + \text{QSD terms.} \qquad (7)$$

This form arises as it is models the preservation of semantic information, by means of a unitary time evolution, even in the presence of the noise in the QSD terms. We thus see the origin of the Hilbert space structure of quantum phenomena. Because of the QSD noise (7) is an irreversible quantum system. The time step Δt in (7) is relative to the scale of the fractal processes being explicitly described, as we are using a configuration space of mappings between prescribed gebits. At smaller scales we would need a smaller value of Δt. Clearly this invokes a (finite) renormalisation scheme. We now discuss the form of the hamiltonian and the Quantum State Diffusion (QSD) terms.

First (7), without the QSD term, has a form analogous to a 'third quantised' system, in conventional terminology [26]. These systems were considered as perhaps capable of generating a quantum theory of gravity. The argument here is that this is the emergent behaviour of the SNN, and it does indeed lead to quantum gravity, but with quantum matter as well. More importantly we understand the origin of (7), and it will lead to quantum and then classical gravity, rather than arise from classical gravity via some ad hoc or heuristic quantisation procedure.

Depending on the 'peaks' of Ψ and the connectivity of the resultant dominant mappings such mappings are to be interpreted as either embeddings or links; Fig.5c then suggests the dominant process-space form within Ψ showing both links and embeddings. The emergent process-space then has the characteristics of a quantum foam. Note that, as indicated in Fig.5c, the original start-up links and nodes are now absent. Contrary to the suggestion in Fig.5c, this process space cannot be embedded in a *finite* dimensional geometric space with the emergent metric preserved, as it is composed of nested or fractal finite-dimensional closed spaces.

We now consider the form of the hamiltonian H. The previous section suggested that Manton's non-linear elasticity interpretation of the Skyrme energy is appropriate to the SNN. This then suggests that H is the functional operator

$$H = \sum_{\alpha \neq \beta} h[\frac{\delta}{\delta \pi_{\alpha\beta}}, \pi_{\alpha\beta}], \qquad (8)$$

where $h[\frac{\delta}{\delta\pi}, \pi]$ is the (quantum) Skyrme Hamiltonian functional operator for the system based on making fuzzy the mappings $\pi : S \to \Sigma$, by having h act on wave-functionals of the form $\Psi[\pi(x); t]$. Then H is the sum of pairwise embedding or homotopy hamiltonians. The corresponding functional Schrödinger equation would simply describe the time evolution of quantised Skyrmions with the base space fixed, and $\Sigma \in SU(2)$. There have been very few analyses of even this class of problem, and then the base space is usually taken to be E^3. We shall not give the explicit form of h as it is complicated, but wait to present the associated action.

In the absence of the QSD terms the time evolution in (7) can be formally written as a functional integral

$$\Psi[\{\pi_{\alpha\beta}\}; t'] = \int \prod_{\alpha \neq \beta} \mathcal{D}\tilde{\pi}_{\alpha\beta} e^{iS[\{\tilde{\pi}_{\alpha\beta}\}]} \Psi[\{\pi_{\alpha\beta}\}; t], \qquad (9)$$

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where, using the continuum t limit notation, the action is a sum of pairwise actions,

$$S[\{\tilde{\pi}_{\alpha\beta}\}] = \sum_{\alpha \neq \beta} S_{\alpha\beta}[\tilde{\pi}_{\alpha\beta}], \tag{10}$$

$$S_{\alpha\beta}[\tilde{\pi}] = \int_t^{t'} dt'' \int d^n x \sqrt{-g} \left[\frac{1}{2} \mathrm{Tr}(\partial_\mu \tilde{U} \tilde{U}^{-1} \partial^\mu \tilde{U} \tilde{U}^{-1}) + \frac{1}{16} \mathrm{Tr}[\partial_\mu \tilde{U} \tilde{U}^{-1}, \partial^\nu \tilde{U} \tilde{U}^{-1}]^2 \right], \tag{11}$$

and the now time-dependent (indicated by the tilde symbol) mappings $\tilde{\pi}$ are parametrised by $\tilde{U}(x,t)$, $\tilde{U} \in S_\alpha$. The metric $g_{\mu\nu}$ is that of the n-dimensional base space, S_β, in $\pi_{\alpha,\beta} : S_\beta \to S_\alpha$. As usual in the functional integral formalism the functional derivatives in the quantum hamiltonian, in (8), now manifest as the time components ∂_0 in (11), so now (11) has the form of a 'classical' action, and we see the emergence of 'classical' fields, though the emergence of 'classical' behaviour is a more complex process. Eqns.(7) or (9) describe an infinite set of quantum skyrme systems, coupled in a pairwise manner. Note that each homotopic mapping appears in both orders; namely $\pi_{\alpha\beta}$ and $\pi_{\beta\alpha}$.

The Quantum State Diffusion (QSD) [27] terms are non-linear and stochastic,

$$\text{QSD terms} = \sum_\gamma \left(<L_\gamma^\dagger> L_\gamma - \frac{1}{2} L_\gamma^\dagger L_\gamma - <L_\gamma^\dagger><L_\gamma> \right) \Psi \Delta t + \sum_\gamma \left(L_\gamma - <L_\gamma> \right) \Psi \Delta \xi_\gamma, \tag{12}$$

which involves summation over the class of Linblad functional operators L_γ. The QSD terms are up to 5th order in Ψ, as in general,

$$<A>_t = \int \prod_{\alpha \neq \beta} \mathcal{D}\pi_{\alpha\beta} \Psi[\{\pi_{\alpha\beta}\}; t]^* A \Psi[\{\pi_{\alpha\beta}\}; t], \tag{13}$$

and where $\Delta \xi_\gamma$ are complex statistical variables with means $M(\Delta \xi_\gamma) = 0$, $M(\Delta \xi_\gamma \Delta \xi_{\gamma'}) = 0$ and $M(\Delta \xi_\gamma^* \Delta \xi_{\gamma'}) = \delta(\gamma - \gamma') \Delta t$

These QSD terms are ultimately responsible for the emergence of classicality via an objectification process, but in particular they produce wave-function(al) collapses during quantum measurements, as the QSD terms tend to 'sharpen' the fuzzy homotopies towards classical or sharp homotopies (the forms of the Linblads will be discussed in detail elsewhere). So the QSD terms, as residual SRN effects, lead to the Born quantum measurement random behaviour, but here arising from the process physics, and not being invoked as a metarule. Keeping the QSD terms leads to a functional integral representation for a density matrix formalism in place of (9), and this amounts to a derivation of the decoherence formalism which is usually arrived at by invoking the Born measurement metarule. Here we see that 'decoherence' arises from the limitations on self-referencing.

In the above we have a deterministic and unitary evolution, tracking and preserving topologically encoded information, together with the stochastic QSD terms, whose form protects that information during localisation events, and which also ensures the full matching in QHFT of process-time to real time: an ordering of events, an intrinsic direction or 'arrow' of time and a modelling of the contingent present moment effect. So we see that process physics generates a complete theory of quantum measurements involving the non-local, non-linear and stochastic QSD terms. It does this because it generates both the 'objectification' process associated with the classical apparatus and the actual process of (partial) wavefunctional collapse as the quantum modes interact with the measuring apparatus. Indeed many of the mysteries of quantum measurement are resolved when it is realised that it is the measuring apparatus itself that actively provokes the collapse, and it does so because the QSD process is most active when the system deviates strongly from its dominant

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mode, namely the ongoing relaxation of the system to a 3D process-space, and matter survives only because of its topological form. This is essentially the process that Penrose [28] suggested, namely that the quantum measurement process is essentially a manifestation of quantum gravity. The demonstration of the validity of the Penrose argument of course could only come about when quantum gravity was *derived* from deeper considerations, and not by some *ad hoc* argument such as the *quantisation* of Einstein's classical spacetime model.

The mappings $\pi_{\alpha\beta}$ are related to group manifold parameter spaces with the group determined by the dynamical stability of the mappings. This symmetry leads to the flavour symmetry of the standard model. Quantum homotopic mappings or skyrmions behave as fermionic[4] or bosonic modes for appropriate winding numbers; so process physics predicts both fermionic and bosonic quantum modes, but with these associated with topologically encoded information and not with objects or 'particles'.

6   Quantum Field Theory

The QHFT is a very complex 'book-keeping' system for the emergent properties of the neural network, and we now sketch how we may extract a more familiar quantum field theory (QFT) that relates to the standard model of 'particle' physics. An effective QHFT should reproduce the emergence of the process-space part of the quantum foam, particularly its 3D aspects. The QSD processes play a key role in this as they tend to enhance classicality. Hence at an appropriate scale QHFT should approximate to a more conventional QFT, namely the emergence of a wave-functional system $\Psi[U(x); t]$ where the configuration space is that of homotopies from a 3-space to $U(x) \in G$, where G is some group manifold space. This G describes 'flavour' degrees of freedom. So we are coarse-graining out the gebit structure of the quantum-foam. Hence the Schrödinger wavefunctional equation for this QFT will have the form

$$\Psi[U; t + \Delta t] = \Psi[U; t] - iH\Psi[U; t]\Delta t + \text{QSD terms}, \tag{14}$$

where the general form of H is known, and where a new residual manifestation of the SRN appears as the new QSD terms. This system describes skyrmions embedded in a continuum space. It is significant that such Skyrmions are only stable, at least in flat space and for static skyrmions, if that space is 3D. This tends to confirm the observation that 3D space is special for the neural network process system. Again, in the absence of the QSD terms, we may express (15) in terms of the functional integral

$$\Psi[U; t'] = \int \mathcal{D}\tilde{U} e^{iS[\tilde{U}]} \Psi[U; t]. \tag{15}$$

To gain some insight into the phenomena present in (14) or (15), it is convenient to use the fact that functional integrals of this Skyrmionic form my be written in terms of Grassmann-variable functional integrals, but only by introducing a fictitious 'metacolour' degree of freedom and associated coloured fictitious vector bosons. This is essentially the reverse of the Functional Integral Calculus (FIC) hadronisation technique in the Global Colour Model (GCM) of QCD [29]. The action for the Grassmann and vector boson part of the system is of the form (written for flat space)

$$S[\overline{p}, p, A_\mu^a] = \int d^4x \left(\overline{p}\gamma^\mu(i\partial_\mu + g\frac{\lambda^a}{2}A_\mu^a)p - \frac{1}{4}F_{\mu\nu}^a(A)F^{a\mu\nu}(A) \right), \tag{16}$$

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[4]However in order to establish fermionic behaviour a Wess-Zumino process must be extracted from the iterator behaviour or the QHFT. Such a WZ process is time-dependent, and so cannot arise from the frozen SRN argument in Sect.4.

where the Grassmann variables $p_{fc}(x)$ and $\overline{p}_{fc}(x)$ have flavour and metacolour labels. The Skyrmions are then re-constructed, in this system, as topological solitons formed from the low energy Nambu-Goldstone modes; other emergent modes are of higher energy and can be ignored. These coloured and flavoured but fictitious fermionic fields $\overline{p}$ and p correspond to the proposed preon system [30, 31]. As they are purely fictitious, in the sense that there are no excitations in the system corresponding to them, the metacolour degree of freedom must be hidden or confined. We thus arrive at the general feature of the standard model of particles with flavour anf confined colour degrees of freedom. Then while the QHFT and the QFT represent an induced syntax for the semantic information, the preons may be considered as an induced 'alphabet' for that syntax. The advantage of introducing this preon alphabet is that we can more easily determine the states of the system by using the more familiar language of fermions and bosons, rather than working with the skyrmionic system, so long as only colour singlet states are finally permitted. However it is important to note that (16) and the action in (15) are certainly not the final forms. Further analysis will be required to fully extract the induced actions for the emergent QFT.

7   Inertia and Gravity

Process physics predicts that the neural network behaviour will be characterised by a growing 3-dimensional process-space having, at a large scale, the form of a S^3 hypersphere, which is one of the forms allowed by Einstein's syntactical modelling. It is possible to give the dominant rate of growth of this hypersphere. However first, from random graph theory [32], we expect more than one such spatial system, with each having the character of a growing hypersphere, and all embedded in the random background discussed previously. This background has no metric structure, and so these various hyperspheres have no distance measure over them. We have then a multi-world universe (our 'universe' being merely one of these 'worlds'). Being process spaces they compete for new gebits, and so long as we avoid a saturation case, each will grow according to

$$\frac{dN_i}{dt} = aN_i - bN_i \qquad a > 0, b > 0, \tag{17}$$

where the last term describes the decay of gebits at a rate b, while the first describes growth of the ith 'world', this being proportional to the size (as measured by its gebit content number) $N_i(t)$ as success in randomly attaching new gebits is proportional to the number of gebits present (the 'stickiness' effect), so long as we ignore the topological defects (quantum 'matter') as these have a different stickiness, and also affect the decay rate, and so slow down the expansion. Thus $N_i(t)$ will show exponential growth, as appears to be the case as indicated by recent observations of very distant supernovae counts [33]. Hence process physics predicts a positive cosmological constant, and that this is unrelated to the phenomenon of gravity. Indeed this multi-world model is incompatible with general relativity, as it is not capable of even describing the non-geometric background or embedding system. In this enlarged cosmology each world would have its own independent big-bang beginning, but then it is no longer necessary for this on-going ensemble of worlds to have had a beginning itself, as we may presumably take the system start-up time to $-\infty$. Hence the observation of the cosmological constant effect is here to be interpreted as arising from the existence of these other worlds.

One striking outcome of process physics is an explanation for the phenomenon of gravity. First note that matter is merely topological defects embedded in the process space, and we expect such defects to have a larger than usual gebit connectivity; indeed matter is a violation of the 3-D connectivity of this space, and it is for this reason we needed to introduce fields to emulate this

extra non-spatial connectivity. One consequence of this is that in the region of these matter fields the gebits decay faster, they are less sticky because of the extra connectivity. Hence in this region, compared to other nearby matter-free regions the gebits are being 'turned over' more frequently but at the same time are less effective in attracting new gebits. Overall this suggests that matter-occupying-regions act as net sinks for gebits, and there will be a trend for the neighbouring quantum foam to undergo a diffusion/relaxation process in which the foam effectively moves towards the matter: matter acts as a sink for space, but never as a source. Such a process would clearly correspond to gravity. As the effect is described by a net diffusion/relaxation of space which acts equally on all surrounding matter, the in-fall mechanism is independent of the nature of the surrounding matter. This is nothing more than Einstein's Equivalence Principle. As well if the in-fall rate exceeds the rate at which 'motion' through the process-space is possible then an event horizon appears, and this is clearly the black hole scenario. Presumably at the core of a black-hole is a tangle of topological defects, so that the effective dimensionality is very high, and which maintains the in-flow of quantum foam. Then here the General Relativity formalism fails.

Finally we mention one long standing unsolved problem in physics, namely an understanding of inertia. This is the effect where objects continue in uniform motion unless acted upon by 'forces', and was first analysed by Galileo in the modern era, but of course Zeno made an early attempt. However there has never been an explanation for this effect; in Newtonian physics it was built into the syntactical description rather than being a prediction of that modelling. Of course current physics is essentially a static modelling of reality, with motion indirectly accessed via the geometrical-time metarule, and so the failure to explain motion is not unexpected. However process physics offers a simple explanation.

The argument for inertia follows from a simple self-consistency argument. Suppose a topological defect, or indeed a vast bound collection of such defects, is indeed 'in motion'. This implies that the gebits are being preferentially replaced in the direction of that 'motion', for motion as such is a self-replication process; there is no mechanism in process physics for a fixed pattern to say 'slide' *through* the quantum-foam. Rather motion is self-replication of the gebit connectivity patterns in a set direction. Since the newest gebits, and hence the stickiest gebits, in each topological defect, are on the side corresponding to the direction of motion, the gebits on that side are preferentially replaced. Hence the motion is self-consistent and self-perpetuating.

An additional effect expected in process physics is that such motion results in a time dilation and length contraction effects; the self-replication effect is to be considered as partly the self-replication associated with any internal oscillations and partly self-replication associated with 'motion'. This 'competition for resources' results in the slowing down of internal oscillations, an idea discussed by Toffoli [34]. Such effects have been seen in a variety of 'non-relativistic' continuum systems [35], and indeed they have a long history. In particular emergent Lorentz symmetry has been analysed in the modelling of dislocations in crystals [36], where 'breather modes' as solitons arise. Hence the lesson is that emergent Lorentz symmetry is generic whenever there is a unification of the substratum system and embedded excitations, here the soliton as a dynamical emergent feature within some dynamical background, rather than being merely 'pasted' onto some *a priori* geometrised and so structureless background. Bell [39] has argued for this dynamical interpretation of Lorentz symmetry, as indeed did H.A. Lorentz himself, until this view was overwhelmed by the Einstein interpretation of this symmetry. This is discussed in more detail in the next section. More recently similar ideas have emerged [37, 38] in the analysis of the sound waves in classical fluids. Here we assume that the QHFT will also display these generic Lorentzian dynamical effects, namely the time-dilation/length-contraction effects.

Geometry is clearly an emergent but approximate phenomenological language; it is certainly

not fundamental, and the implicit assumption in physics that it is fundamental has caused many problems and confusions.

There is one further novel effect that is of some significance. The quantum-foam appears to represent a special frame of reference, but one that is well hidden by the time-dilation and length contraction effects. Hence we would not expect a Michelson-Morley type experiment to reveal this frame. However using the arguments of Hardy [40] and Percival [41] we expect that the action of the QSD wavefunctional 'collapse' processes would reveal the actual frame through a multi-component EPR experiment, as the non-local QSD collapse occurs in a truly simultaneous manner. By not using the non-local quantum collapse process we are essentially deceived by the subtle effects of the quantum foam dynamics, as we shall now see.

8 General Relativity

It is essentially straightforward to derive the formalism of general relativity from the above considerations of the behaviour of the quantum foam, with the key steps following the work of Kirkwood in 1953 [42, 43]; see also the recent work by Martin [44]. Assuming that the diffusion/relaxation of the quantum foam in the presence of matter may be described, at the classical level, by a flow field with velocity $\mathbf{v}(\mathbf{r}, t)$, and that some classical test object has velocity $\mathbf{v}_0(t) = d\mathbf{r}(t)/dt$, where $\mathbf{r}(t)$ is the position of the object, hence some cosmological coordinate system is invoked[5]. Then the key measure is the velocity of the object relative to the foam,

$$\mathbf{v}_R(t) = \mathbf{v}_0(t) - \mathbf{v}(\mathbf{r}(t), t), \tag{18}$$

where the foam flow may be explicitly time-dependent. The key assertion is then that the change in this relative velocity, in the presence of a non-gravitational force F, is given by [42],

$$\frac{d}{dt}\left(m(\mathbf{v}_R)\mathbf{v}_R\right) = F - m(\mathbf{v}_R)(\mathbf{v}_R.\nabla).\mathbf{v}(\mathbf{r}, t), \tag{19}$$

which is non-linear as

$$m(\mathbf{v}_R) = \frac{m_0}{\sqrt{(1 - \frac{\mathbf{v}_R^2}{c^2})}}, \tag{20}$$

is the usual speed-dependent effective mass from the Lorentzian dynamics for an object with rest mass m_0, which goes along with time dilations and length contractions caused by effective 'motion' through the quantum foam. In keeping with the equivalence principle m_0 cancels from the equation, when $F = 0$, and we consider only this case in the following. Here c is the maximum speed of any disturbance through the quantum foam, and is clearly relative to the foam. The effective force on the RHS of (19) follows from the usual fluid mechanics expression for the acceleration of the fluid. Note that the denominator in (20) immediately leads to event horizon effects wherever $|\mathbf{v}| = c$, where the region where $|\mathbf{v}| < c$ is inaccessible from the region where $|\mathbf{v}| > c$.

As Kirkwood showed the general relativity formalism of test object trajectories essentially follows from (19) even though it has no notion of curvature or even of general covariance. The only real curvature from process-physics is the cosmological curvature, and this is not related to gravity. As we shall see the curvature of general relativity actually arises from introducing the

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[5]Some discussion of this is in [42, 44], though it requires much more analysis. Possibly the non-local connections in the QHFT provide some preferred frame, coinciding wth the CBR isotropic frame. The time t in (18), (19), etc is presumably the iterator time, since this is also the time that indicates non-local simultaneous wavefunctional collapses. So it appears that the process $t - r$ frame may be defined by quantum non-locality effects.

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classical 'spacetime' measurement protocol, and so is potentially misleading though not without practical use. This protocol also results in the formalism of general covariance. The key dynamics is not that of the fictitious spacetime metric but rather the non-linear dynamics of the quantum flow, and in this regard the successes of general relativity should be regarded as providing valuable clues regarding the foam. We shall now show from (19) and the Lorentz effects how the language of general relativity (GR) arises. Eqn.(19) may be written as

$$\frac{d\mathbf{v}_R(t)}{dt} = -(\mathbf{v}_R(\mathbf{r}, t).\nabla).\mathbf{v}(\mathbf{r}, t) - \frac{1}{m}\frac{dm}{dt}\mathbf{v}_R(t). \tag{21}$$

Evaluating the dm/dt term and solving for $d\mathbf{v}_R/dt$, we obtain

$$\frac{d\mathbf{v}_R(t)}{dt} = -(\mathbf{v}_R(t).\nabla).\mathbf{v}(\mathbf{r}, t) + \frac{1}{c^2}(\mathbf{v}_R(t).(\mathbf{v}_R(\mathbf{r}, t).\nabla)\mathbf{v}(\mathbf{r}, t))\mathbf{v}_R(t), \tag{22}$$

which is cubic in $\mathbf{v}_R$. The event horizon effect is now more subtle. Now (21) or (22) is nothing more than the Euler-Lagrange equation from minimising the functional

$$\tau[\mathbf{v}_0, \mathbf{v}] = \int dt\sqrt{(1 - \frac{\mathbf{v}_R^2}{c^2})} \tag{23}$$

with respect to $\mathbf{r}(t)$, for the case of an irrotational flow $\nabla \times \mathbf{v} = \mathbf{0}$. Eqn.(23) looks very non-GR involving as it does a velocity relative to the flowing foam and the speed c also relative to the foam. However (23) gives

$$d\tau^2 = dt^2 - \frac{1}{c^2}(d\mathbf{r}(t) - \mathbf{v}(\mathbf{r}(t), t)dt)^2, \tag{24}$$

which is the Panlevé-Gullstrand form of the metric [45, 46] for GR restricted to the object trajectory, and is very suggestive. However to fully recover the GR formalism we need to explicitly introduce the spacetime measurement protocol, and the peculiar effects that it induces for the observers historical records.

The quantum foam, it is argued, induces actual dynamical time dilations and length contractions in agreement with the Lorentz interpretation of special relativistic effects. Then observers in uniform motion 'through' the foam will, on measurement say of the speed of light, obtain always the numerical value c. To see this explicitly consider how various observers $O, P, Q, ..$, in different relative motions through the foam, measure the speed of light. They each acquire a standardised rod of length l_0, and then measure the time Δt_0, using an accompanying standardised clock, for a light pulse to travel to one end and be reflected back to the starting end. The observed speed of light is defined for any observer using $c_P =$distance travelled/time duration. For an observer and rod at rest wrt the foam, we get $c_P = c$. However the real Lorentzian dynamics mean that the length of the moving rod is reduced to $l = l_0\sqrt{(1 - v_R^2/c^2)}$ and its clock time is reduced to $\Delta t = \Delta t_0\sqrt{(1-v_R^2/c^2)}$, and then $c_P = 2l/\Delta t = 2l_0/\Delta t_0 = c$. Hence the Lorentzian dynamics results in all observers assigning the same speed c to light; using classical protocols they are unaware of the underlying Lorentzian dynamics at work. The classical spacetime measurement protocol of the observers is based on this effect, namely that the observed speed of light is always c, and that even observers in relative motion agree on this one value.

To be explicit the measurement protocol actually exploits this subtle effect by using the radar method for assigning historical spacetime coordinates to an event: the observer records the time of emission and reception of radar pulses ($t_r > t_e$), and then retrospectively assigns the time and distance of an event B according to (ignoring directional information for simplicity)

$$T_B = \frac{1}{2}(t_r + t_e), \quad D_B = \frac{c}{2}(t_r - t_e), \tag{25}$$
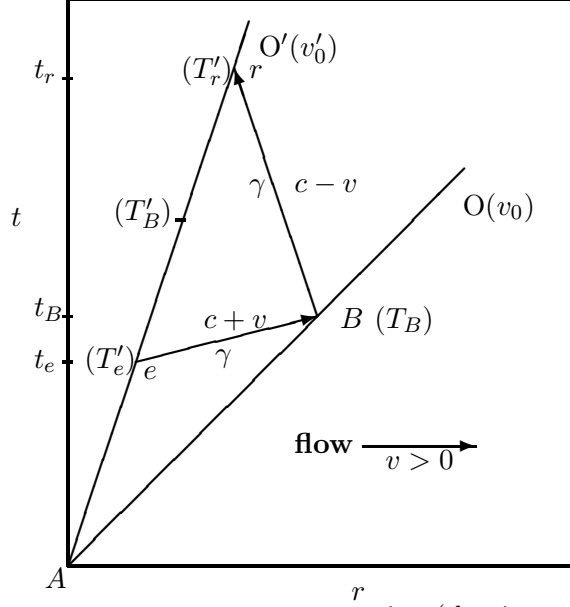
19

Figure 6: A process-time - process-space $t - r$ representation (showing only one spatial direction) of two observers O and O' moving in the direction of the effective flow of the quantum foam, with speeds v_0 and v'_0 with respect to (wrt) the frame r, and so with speeds $v_R = v_O - v$ and $v'_R = v'_0 - v$, wrt to the foam. The diagram is drawn for the case $v > 0$. The flow is assumed to be uniform over the scale of these events. Event A is when both observers pass, and is also used to define zero time and zero distance for all systems, for convenience. Observer O' emits a pulse of light (γ) at event e, which propagates through the foam with speed c, but with speed $c + v$ wrt to the $t - r$ frame, and which is reflected from observer O at event B, and propagates back to O' against the flow with speed $c - v$, and is received by O' at event r. Times in brackets ( ) are the protocol times assigned to various events by the observers. For example T'_B is the time of event B assigned by O' using the spacetime measurement protocol, Eqn.(25). As discussed in the text, the measurement protocol results in such observers introducing a pseudo-Riemannian curved spacetime construct to record and relate the history of such restricted 'classical' events. In this way the protocol induces the syntax of general covariance.

where each observer is now using the same numerical value of c. The event B is then plotted as a point in an individual geometrical construct by each observer, known as a spacetime record, with coordinates (D_B, T_B). This is no different to a historian recording events according to some agreed protocol. Unlike historians, who don't confuse history books with reality, physicists do so. We now show that, because of this protocol and the quantum foam dynamical effects, observers will discover, on comparing their historical records of the same events, that the expression

$$\tau^2_{AB} = T^2_{AB} - \frac{1}{c^2} D^2_{AB} \tag{26}$$

is an invariant, where $T_{AB} = T_A - T_B$ and D_{AB} are the difference in times and distances assigned to events A and B using the measurement protocol (25), so long as both are sufficiently small compared with the scale of inhomogeneities in the velocity field. We now demonstrate this for the situation illustrated in Fig.6. For observer O:

$$\tau^2_{AB} = T^2_B = t^2_B(1 - \frac{v^2_R}{c^2}), \tag{27}$$

since $T_A = 0$ and $D_{AB} = 0$, while for observer O':

$$\tau'^2_{AB} = T'^2_B - \frac{1}{c^2} D'^2_B = \frac{1}{4}(T'_r + T'_e)^2 - \frac{1}{4}(T'_r - T'_e)^2 = T'_r T'_e = t_r t_e(1 - \frac{v'^2_R}{c^2}). \tag{28}$$

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Now from Fig.6 we note the distance relationships

$$(c + v)(t_B - t_e) = v_o t_B - v'_0 t_e, \quad (c - v)(t_r - t_B) = v_o t_B - v'_0 t_r, \tag{29}$$

from which we obtain

$$t_r t_e = \frac{1 - \dfrac{v_R^2}{c^2}}{1 - \dfrac{v_R'^2}{c^2}} t_B^2, \tag{30}$$

and we see, from (27), (28) and (30), that $\tau_{AB}^2 = \tau_{AB}'^2$. Hence the protocol and Lorentzian effects result in the construction in (26) being indeed an invariant. This is a remarkable and subtle result. For Einstein this invariance was a fundamental assumption, but here it is a derived result. Explicitly indicating small quantities by Δ prefixes, and on comparing records retrospectively, an ensemble of nearby observers agree on the invariant

$$\Delta \tau^2 = \Delta t^2 - \frac{1}{c^2} \Delta d^2, \tag{31}$$

for any two nearby events. This implies that their individual patches of spacetime records may be mapped one into the other merely by a change of coordinates, and that collectively the space-time patches of all may be represented by one pseudo-Riemannian manifold, where the choice of coordinates for this manifold is arbitrary, and we finally arrive at the invariant

$$\Delta \tau^2 = g_{\mu\nu}(x) \Delta x^\mu \Delta x^\nu. \tag{32}$$

Of course this spacetime construction loses the experiential time effects, and is indeed a static non-processing historical record, and is nothing more than a very refined history book, with the shape of the manifold encoded in a metric tensor $g_{\mu\nu}(x)$. However this encodes two quite distinct processes, the velocity flow field of the quantum foam and as well the measurement protocol. Enormous confusion enters if we do not keep these two aspects in mind. Of course it is utterly nonsensical to assert that this spacetime construct *is* reality. In general (32) may be reduced to the Panlevé-Gullstrand form (24), but now not restricted to events on the trajectory of an object, that is to space-like events (this requires further constructive analysis similar to that in Fig.6). By in part requiring agreement with Newtonian gravity Hilbert and Einstein guessed the equation which specifies how matter, and energy-momentum in general, determines $g_{\mu\nu}(x)$,

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = -8\pi G T_{\mu\nu}, \tag{33}$$

where $R_{\mu\nu}$ and R are contractions with $g_{\mu\nu}$ of the curvature tensor $R_{\mu\nu\lambda\kappa}$, and $T_{\mu\nu}$ is the energy-momentum tensor, in the usual manner. This has been tested in a number of situations including, in particular, the indirect evidence of wave phenomena from the studies of binary pulsars. Such gravitational waves are merely the quantum-foam flow pattern adjusting to changes in the sink locations and velocities. However if we remove the measurement protocol effects, and the Panlevé-Gullstrand form of the metric does this, then the Einstein equation (33) should really be regarded as indicating the quantum foam flow dynamics, and how the presence of energy-momentum, that is, topological defects, acting as sinks for the foam, influences that flow. A task of process-physics, using the QHFT, is to derive that dynamics, but the GR equation (33) clearly can provide valuable clues. See [43] for early speculation. The cosmological constant, which arises from a non-gravitational process (Sect.7.) presumably can be included in (33), in a phenomenological manner.

This differential geometry system can be used to determine the trajectories of test objects using the familiar form

$$\Gamma^{\lambda}_{\mu\nu}\frac{dx^{\mu}}{d\tau}\frac{dx^{\nu}}{d\tau} + \frac{d^2x^{\lambda}}{d\tau^2} = 0 \tag{34}$$

which involves the usual affine connection of the spacetime construct, and which arises from minimising the functional

$$\tau[x] = \int dt \sqrt{g^{\mu\nu}\frac{dx^{\mu}}{dt}\frac{dx^{\nu}}{dt}}, \tag{35}$$

wrt to the path $x[t]$. Now (34) must predict the same trajectory as the quantum-foam form (19). It is instructive to consider the special case of a spherically symmetric mass M as the sink for the quantum foam. In the absence of a derivation of the quantum-foam dynamics from the QHFT, like Einstein, we shall assume agreement with Newtonian gravity in the limit of object speeds low relative to c. Then we can neglect the last term in (21), and (21) leads to Newton's equation of motion

$$\frac{d^2\mathbf{r}(t)}{dt^2} = -GM\frac{\hat{\mathbf{r}}}{r^2}, \tag{36}$$

only if the velocity field is the static in-ward flow

$$\mathbf{v}(\mathbf{r}) = -\sqrt{\frac{2GM}{r}}\hat{\mathbf{r}}. \tag{37}$$

Then with this velocity field the Panlevé-Gullstrand metric becomes, and now being now valid for events not on the trajectory of the object, and with spherical symmetry,

$$d\tau^2 = dt^2 - \frac{1}{c^2}(dr + \sqrt{\frac{2GM}{r}}dt)^2 - \frac{1}{c^2}r^2d\theta^2, \tag{38}$$

which, under the change of coordinate,

$$t' = t - \frac{2}{c}\sqrt{\frac{2GMr}{c^2}} + \frac{4GM}{c^2}\tanh^{-1}\sqrt{\frac{2GM}{c^2r}}, \tag{39}$$

we obtain the Schwarzschild form of the metric

$$d\tau^2 = (1 - \frac{2GM}{c^2r})dt'^2 - \frac{r^2d\theta^2}{c^2} - \frac{dr^2}{c^2(1 - \frac{2GM}{c^2r})}, \tag{40}$$

which is a particular solution of (33). Hence using this form of the metric and (34) we obtain the same trajectory predictions as from (19), modulo the measurement protocol [6]. Of course while the measurement protocol has confused the nature of the dynamics encoded in the GR equations, the GR equations nevertheless can be helpful when doing observations with electromagnetic signalling, since they then also encode the effects of the quantum foam on the observers instruments, particularly time and/or frequency measurements, as for example in the GPS navigation system.

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[6]Eqn.(22), for the static and spherically symmetric flow of (37), has circular orbits for which $(\mathbf{v}_R(t).(\mathbf{v}_R(t).\nabla).\mathbf{v}(\mathbf{r},t)) = 0$. There are also elliptical orbits, but because then $(\mathbf{v}_R(t).(\mathbf{v}_R(t).\nabla).\mathbf{v}(\mathbf{r},t)) \neq 0$ this term causes the ellipse to precess in the direction of motion (i.e. an advance of the perihelion), and the rate of this precession is determined in part by the eccentricity of the orbit, but is zero for zero eccentricity. However the approximate analysis of (34) for elliptical orbits (see for example S. Weinberg, *Gravitation and Cosmology*, p.194) gives the well known form $\Delta\phi = 6\pi GM/c^2(1-e)a$ for the precession, but this is non-zero for circular orbits ($e = 0$), which is a strange result. This suggests that there is a residual protocol or coordinate-time effect that arises in using the Schwarzschild metric, and that the analysis needs to be reviewed.

9 Conclusions

Presented herein is the current state of development of the radical proposal that to comprehend reality we need a system richer than mere syntax to capture the notion that reality is at all levels about, what may be called, internal, relational or semantic information, and not, as in the case of syntax, information that is essentially accessible to or characterisable by observers, and that approach amounts to the assertion that reality can and should be modelled by symbol manipulating exercises, according to some externally imposed set of *laws*. This necessitates an evolution in modelling reality from a non-process physics to a process physics. Such a development has been long anticipated, with such insights dating back 2500 years to Heraclitus.

In particular process physics has now provided a derivation of Einstein's General Relativity model, as being a manifestation of various effects of the emergent quantum foam system within process physics. The quantum foam is the long sought for quantum theory of gravity, as encoded by the Quantum Homotopic Field Theory. However the higher level General Relativity, and its key concept of *spacetime*, turns out to be essentially a phenomenological construct, and not at all fundamental. The same applies to the technical aspect of General Covariance. This non-processing static spacetime construct, with its representation of gravitational effects by means of Riemannian curvature, turns out to be based on two essentially separate effects of the quantum foam, the first being the apparent invariance of the speed of light for any observer, which is caused by actual Lorenztian dynamical effects upon clocks and rods, and which nevertheless provides the classical measurement protocol which is used in practical observations, but which is invalidated by non-local quantum processes of the Einstein, Poldolsky and Rosen type. The second effect is the effective diffusion/relaxation of the quantum foam towards quantum 'matter', and this is the gravity effect. Amalgamating the two effects results in the spacetime construct, but the curvature is induced by the peculiar aspects of the measurement protocol. The genuine gravitational effects may be seen only after the removal of these effects. In this way the Einstein field equations then come down to assertions about the quantum foam velocity field behaviour. Having exposed this dynamics, and as well indicating the generic origin of the Lorentzian dynamical effects, the direction of future research work in process physics becomes clear.

To realise the process physics one representation has been proposed and studied, namely that of a self-referentially limited neural-network model, for neural networks are powerful examples of non-symbolic information processing. This neural-network model is manifestly free of any notions of geometry, quantum phenomena or even 'laws of physics'. Its origin was the observation that beneath quantum field theory is essentially a neural network activity, and which now appears to be necessitated by the Gödelian limitations on syntactical systems, and the generalisation of theoretical physics modelling of reality from syntax to semantics. The arguments presented here go a long way in demonstrating that the phenomena of space, the quantum and the time effects are emergent in the neural network, but only because the self-referential noise acts as a source of negentropy or order. This self-referential noise is a new fundamental aspect of reality. It effects have been apparent ever since man became aware of experiential time, with its dominant manifestation of the *Now*, and which physics has so strongly denied. Of course the enormous success of the geometrical modelling of time and its associated mechanical clock-work determinism has long overwhelmed physics. Process physics has re-affirmed that time is different to space. Poincaré and others, particularly the process philosophers, had noticed that determinism implies, in principle, that since the 'future' (or is it the 'past'?) is entirely locked in, determinism forbids any experiential *Now*. Einstein thought that this was unavoidable, but of course he was profoundly opposed to intrinsic randomness, and so overlooked its enormous role in reality. This self-referential noise

was also apparent in the discovery of the randomness of the quantum measurement process, but the mechanical mindset of physicists was quickly reassured with the Born quantum measurement metarule; that we switch from wave phenomena to Democritean 'particles' to explain spots or clicks in detectors.

The process physics model has been developed to the stage where various phenomena have been identified and appropriate induced syntactical descriptions have been suggested. These correspond essentially to the concepts of current physics which, over the years, have been arrived at via increasingly more abstract non-process syntactical modelling. One important addition being the ever-present QSD terms which, as it happens, ensure that the phenomena of time fully matches our experiences of time, and which also plays various other key roles. Only by abandoning the geometric model of time has process physics been able to unify the phenomena of reality, and by demonstrating that all the fundamental phenomena that interest physicists are necessarily emergent, that reality must be just so, and not otherwise. Indeed it is only by confronting the limits of logic and formalism do we actually arrive at an understanding of how such modes of comprehending reality have arisen and why they have been so effective, so much so that their very effectiveness has blinded us to their limitations, and the orthodoxy of the non-process physics approach had become overbearing and even destructive to future physics. This new process-physics is inherently non-reductionist as it explicitly assumes that reality is sufficiently complex that it is self-referential.

Clearly we see the beginnings of a unification of physics that leads to quantum field theory, quantum gravity and classicality and the emergence of syntax and its associated logic of named objects. Such a fundamental change in our comprehension of reality will result in novel technological innovations, and one of these, synthetic quantum systems and their possible role in 'room temperature' quantum computers, has been suggested in [47].

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