Process Physics: Modelling Reality as Self-Organising Information*

Reginald T. Cahill, Christopher M. Klinger and Kirsty Kitto
School of Chemistry, Physics and Earth Sciences
Flinders University
GPO Box 2100, Adelaide 5001, Australia

Abstract

The new *Process Physics* models reality as self-organising relational information and takes account of the limitations of logic, discovered by Gödel and extended by Chaitin, by using the concept of self-referential noise. Space and quantum physics are emergent and unified, and described by a Quantum Homotopic Field Theory of fractal topological defects embedded in a three-dimensional fractal process-space.

*Preview of *Process Physics: The Limits of Logic and the Modelling of Reality*; in preparation.

Modelling Reality

The present day modelling of reality and the mindset of physicists was very much set by the Ancient Greeks some 2,500 years ago, particularly by Democritus with his concept of atoms as objects occupying a position in space. Ever since physicists have believed in objects and their *a priori* rules of behaviour or 'laws of physics' as fundamental to modelling reality. This mode of modelling has been extremely successful. These concepts were clearly abstractions from everyday human experience and culminated, in the case of space, with the Euclidean formalisation of geometry. Great progress followed Galileo's and then Newton's demonstrated successes in using a geometrical model of the phenomena of time, despite the glaring deficiencies of that model, which matches the ordering of events with the ordering of the real numbers, but fails to find a match for the contingent present moment or even the difference between past and present. These were serious problems that persisted in the more elaborate spacetime geometrical model by Einstein and were of great concern to him, but even Einstein doubted that any modelling of time could capture the present moment effect. Significantly, because this static real-number modelling of time fails in these respects, one must always introduce a meta-rule which states that, in essence, one must imagine a point moving along the time-line at a uniform rate; something we always do subconsciously as physicists. We should call this the geometrical-time meta-rule. It is important to note that in Newtonian physics and all that followed the modelling of reality is actually *non process*: there is no sense of anything actually happening. Newton's celebrated equations of motion don't actually describe motion; they describe *static* functions, $x(t)$ say, which we relate to motion by using the geometrical-time meta-rule.

An even greater problem for reality modelling arose with the quantum theory. There static or non-process wave-functions $\psi(x,t)$ were related to motion of the wavefunction by invoking the geometrical-time meta-rule, but that was manifestly inadequate since the clicking of detectors clearly revealed an additional real process that was completely absent in the quantum theory. This mismatch was 'fixed' by Born introducing the quantum measurement meta-rule that states that the probability density of an actual click at location x in a detector at time t is given by $|\psi(x,t)|^2$. Physicists appear to believe that these clicks are to be understood as being produced by objects ('particles'), that are accompanied by $\psi(x,t)$, hitting the detector even though these objects are not mentioned in the quantum mathematical formalism, which deals only with $\psi(x,t)$, say.

The success of physics thus actually arises, in part, from its meta-rules. The need for them, being separate from but consistent with the mathematical formalisms, are indicators of a deep flaw within the current mindset of physicists. An analogous deep flaw in the axiomatic formalisms of mathematics was revealed by Gödel in 1931. He showed that for formalisms (arithmetic initially) sufficiently rich that they support self-referential statements, there exist truths which cannot be proven within the formalism. Chaitin[1], more recently showed that these unprovable truths have the property of randomness; from the point of view of the given formalism they have no explanation. In physics we

[1] G.J. Chaitin, *The Unknowable*, Springer-Verlag, Germany 1999, http://www.cs.auckland.ac.nz/CDMTCS/chaitin/unknowable/index.html

would describe them as un-caused. While physics has never reached the stage of a strict axiomatic formalism, it nevertheless has been travelling in that direction and, like mathematics, there are truths beyond formalism. The absence of such contingent truths has been partialy compensated by the use of meta-rules.

In process physics we present a radical new modelling of reality designed to overcome these and other deep problems within current physics. The key concept is to model reality as self-organising relational information via an order-disorder process system which takes account of the limitations of formalism or logic by using the new concept of self-referential noise (SRN). This SRN is not randomness due to a simple lack of potential knowledge (such as found in statistical physics) but mimics what are *in principle* un-provable or non-algorithmic truths; by using SRN we essentially transcend the limits of logic without being illogical. Logic, it should be noted, is the language of named 'objects'; for this reason we start up process physics using 'pseudo-objects'. The dramatic discovery is that rather than being some impediment to understanding reality Gödel's discovery and its extension to SRN acts as an intrinisic resource within this non-formal system and with which a vastly improved modelling of reality has become possible. By inducing, in approximation, a formal system together with associated emergent meta-rules it links back to and subsumes the current physics modelling of reality. We find that the system operates by forming a dissipative structure, driven by the SRN, and which is characterised by an emergent and expanding three-dimensional fractal process-space in which are embedded self-replicating fractal topological defects, both described in a unified manner by a Quantum Homotopic Field Theory (QHFT). This emergence is a non-algorithmic increase in complexity in the system.

The process modelling of reality dates back to Heraclitus of Ephesus (540-480BC) 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 and the appearance of 'things' depend upon this flux for their continuity and identity. So process physics has also been described as a Heraclitean Process System, with the flux identified with SRN.

Relational Information and Self-Referential Noise

Process physics models reality as a self-organising relational information system, sufficiently rich that self-referencing is possible ('relational information' refers to the idea that information is internal to the system). Curiously a similar task arises in modelling consciousness. For such a system Gödel's key discovery was that truth has no finite description, and we model this, borrowing from Chaitin's work in mathematics, by introducing the concept of an intrinsic randomness which is called self-referential noise (SRN). SRN ensures that most truths are contingent - they are un-caused; a restricted form of determinism is then an emergent feature of process physics.

Because process physics is at its deepest levels an information system and is devoid of objects and their laws it requires a subtle bootstrap mechanism to set it up: we introduce real-number valued connections or relational information strengths B_{ij} between any two pseudo-objects i and j (also called monads after Leibniz who espoused the relational mode of thinking in response to and in contrast to Newton's absolute, ie objective, space and time). These pseudo-objects are to be regarded as temporary scaffolding. They 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 anti-symmetry $B_{ij} = -B_{ji}$ to conveniently ensure that $B_{ii} = 0$. At this stage a key concept of process physics arises: to ensure that the monads are not objects the system must generate linked monads forming a fractal network; then self-consistently the start-up monads may themselves be considered as mere names for sub-networks of relations (for a successful suppression the scheme must display self-organised criticality).

To generate a fractal structure we must use a non-linear iterative system for the B_{ij} values. These iterations amount to the logical necessity to introduce a time-like phenomena into process physics. 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. In this way process physics arrives at a new modelling of time, *process time*, which is much more complex than that introduced by Galileo and reaching its high point with Einstein's spacetime geometrical model. In process physics Einstein's model emerges not as some ontological statement about reality, such as "the universe is 4D geometry", but as the coarse-grained 'history book' of the evolving B_{ij} network. Geometrical time is then merely the pagination of the history book, and this has no ontological reality. The nature of the internal experiential time is complex but we expect time dilation and other manifestations through the Lorentzian explanation; that is, the system mimics covariance effects but is not intrinsically covariant. Such effects are caused by the finite information processing rate.

The process physics concepts have so far only been realised with one particular scheme involving a non-linear matrix iteration with additive SRN w_{ij};

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

The $w_{ij} = -w_{ji}$ are independent random variables for each ij pair and for each iteration, chosen from some probability distribution. We start the iterator at $B \approx 0$ - representing the absence of information. With the noise absent the iterator would converge to a constant matrix. However in the presence of the noise the dominant mode is the formation of a randomised and structureless background. However a significant discovery was that the noisy iterator 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'.

3D Process Space from Self-Assembling Gebits

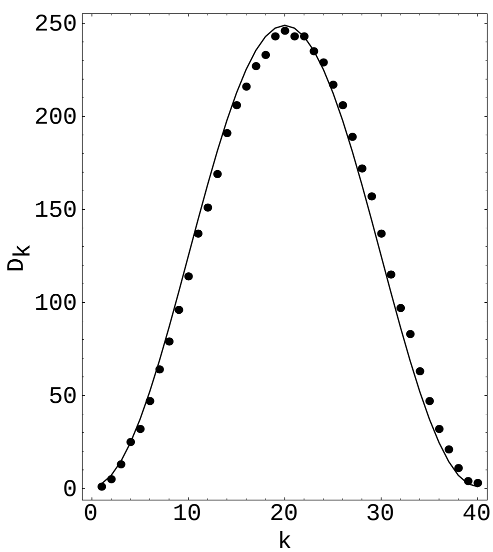
This growing three-dimensional fractal process-space is an example of a Prigogine far-from-equilibrium dissipative structure driven by the SRN. From each iteration the noise term will additively introduce rare large value B_{ij}. These B_{ij}, which define sets of linked monads, will persist through more iterations than smaller valued B_{ij} and, as well, they become further linked by the iterator to form a three-dimensional process-space with embedded topological defects.

To see this consider a monad i involved in one such large B_{ij}; it will be connected via other large B_{ik} to a number of other monads and so on, and this whole set of connected monads forms a unit which we call a gebit as it acts as a small piece 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.

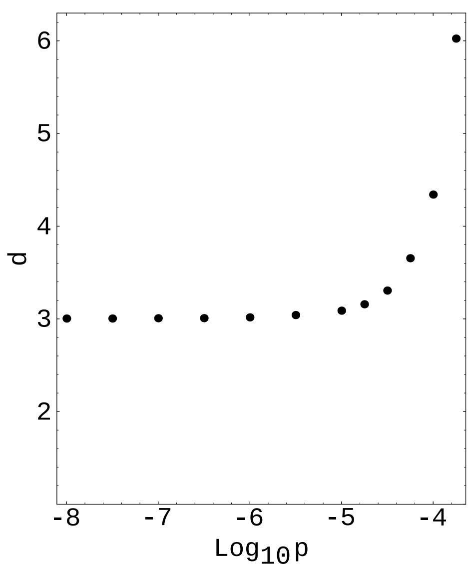
To analyse the connectivity of such gebits assume for simplicity that the large B_{ij} arise with fixed but very small probability p, then the geometry of the gebits is revealed by studying the probability distribution for the structure of the gebits minimal spanning trees with D_k monads at k links from monad i ($D_0 \equiv 1$), this is given by[2]

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

where $q = 1-p$, N is the total number of monads in the gebit and L is the maximum depth from monad 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.1a for $N = 5000$ and $\mathrm{Log}_{10}p = -6$. The resultant d values for a range of $\mathrm{Log}_{10}p$ and $N = 5000$ are shown in fig.1b.



(a)



(b)

Figure 1: (a) Points show the D_k set and $L = 40$ value found by numerically maximising $\mathcal{P}[D,L,N]$ for $\mathrm{Log}_{10}p = -6$ 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.

[2] G. Nagels, *Gen. Rel. and Grav.* **17**, 545 (1985).

This shows, for p below a critical value, that $d = 3$ indicating that the connected monads 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).

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 are singular ($\det(tree) = 0$). 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. If this cross-linking was entirely random then the above analysis could 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.2.

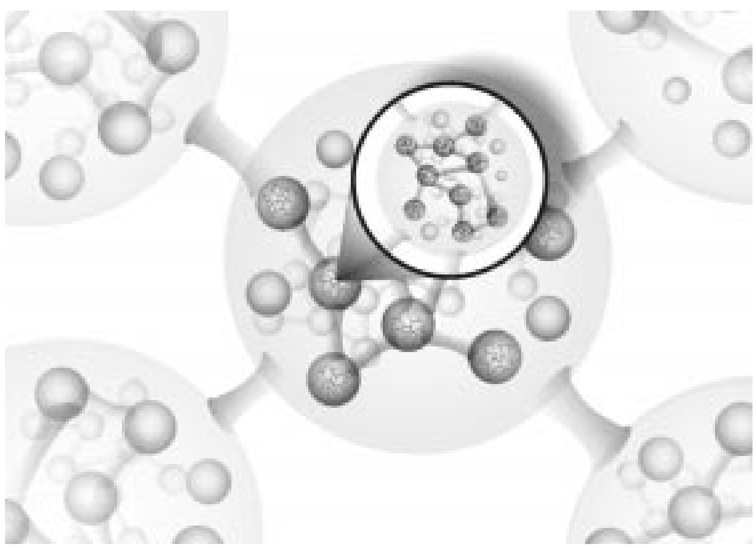


Figure 2: Artist representation (including magnifying glass) of linked and embedded gebits forming a 3D fractal process-space - characterised by a quantum-foam behaviour.

Over ongoing iterations the existing gebits become cross-linked and eventually lose their ability to undergo further linking; they lose their 'stickiness' and decay. 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; by making *a priori* geometrical assumptions about space physicists have inadvertently treated space as an object rather than as a process, and a process requiring more than the geometrical modelling of time. Next we turn to emergent quantum behaviour.

Quantum Homotopic Field Theory

Relative to the iterator the dominant resource is the large valued B_{ij} from the SRN because they form the 'sticky' gebits which are self-assembled into the non-flat compact 3D process-space. The accompanying topological defects within these gebits and also the topological defects within the process space require a more subtle description. The key behavioural mode for those defects which are sufficiently large (with respect to the number of component gebits) is that their existence, as identified by their topological properties, will survive the ongoing process of mutation, decay and regeneration; they are topologically self-replicating. Consider the analogy of a closed loop of string containing a knot - if, as the string ages, we replace small sections of the string by new pieces then eventually all of the string will be replaced; however the relational information represented by the knot will remain unaffected as only the topology of the knot is preserved. In the process-space there will be gebits embedded in gebits, and so forth, in topologically non-trivial ways; the topology of these embeddings is all that will be self-replicated in the processing of the dissipative structure.

To analyse and model the life of these topological defects we need to characterise their general behaviour: if sufficiently large (i) they will self-replicate if topologically non-trivial, (ii) we may apply continuum homotopy theory to tell us which embeddings are topologically non-trivial, (iii) defects will only dissipate if embeddings of 'opposite winding number' (these classify the topology of the embedding) engage one another, (iv) the embeddings will be in general fractal, and (iv) the embeddings need not be 'classical', ie the embeddings will be fuzzy. To track the coarse-grained behaviour of such a system has lead us to the development of a new form of quantum field theory: Quantum Homotopic Field Theory (QHFT)[3]. This models both the process-space and the topological defects.

QHFT has the form of a functional Schrödinger equation for the time-evolution of a wave-functional $\Psi(....,\pi_{\alpha\beta},....,t)$

$$i\hbar\Delta\Psi(....,\pi_{\alpha\beta},....,t) = H\Psi(....,\pi_{\alpha\beta},....,t)\Delta t + \text{QSD terms},$$

where the configuration space is that of all possible homotopic mappings; $\pi_{\alpha\beta}$ maps from S_β to S_α with $S_\gamma \in \{S_1, S_2, S_3, ...\}$ the set of all possible gebits (the topological defects need not be S^3's). 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.2 then suggests the dominant process-space form within Ψ showing both links and embeddings. Space then has the characteristics of Wheeler's quantum foam. We have indicated Planck's constant $\hbar$ to emphasise that 100 years after its discovery we finally

[3]There may be a connection to V. Turaev, *Homotopy field theory in dimension 3 and crossed group-categories*, math.GT/0005291.

have an explanation for its logical necessity in describing reality. Its actual value depends on an arbitrary choice of units; here the natural value is $\hbar = 1$.

There are additional Quantum State Diffusion (QSD)[4] terms which are non-linear and stochastic; 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; a mechanism that eluded quantum theory since its discovery and which is finally seen to have its explanation with Gödel's incompleteness theorem and its associated SRN within a process-system. The random click of the detector is then a manifestation of Geodel's profound insight that truth has no finite description in self-referential systems; the click is simply a random contingent truth. The SRN is thus seen to be a major missing component of the modelling of reality. 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.

The mappings $\pi_{\alpha\beta}$ are related to group manifold parameter spaces with the group determined by the dynamical stability of the mappings, this gauge symmetry leads to the flavour symmetry of the standard model. Quantum homotopic mappings behave as fermionic 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'. Unlike conventional quantum field theory QHFT has fractal embedded fermionic/bosonic modes.

The solution of the Schrödinger functional equation, without the QSD terms, can be expressed as functional integrals; and using functional integral calculus techniques these can be deconstructed down to preon fermionic functional integrals but only by introducing a meta-colour dynamics, with the colour necessarily 'confined' as there are no topological defects corresponding to the preons.

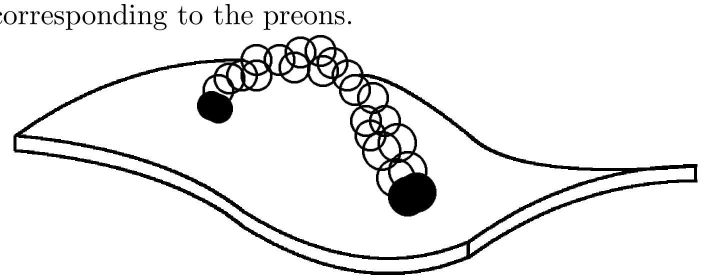


Figure 3: Topologically encoded information non-locally embedded in the process-space with two 'footprints' (process-space drawn as 2D with thickness and not showing gebit structure).

The topologically encoded information may have more than one 'foot-print' in the process-space, as indicated in fig.3. In the induced approximate formal standard quantum theory they correspond to the superpositions $\psi_1(x) + \psi_2(x)$. So we also finally understand

[4] I.C. Percival, *Quantum State Diffusion*, Cambridge Univ. Press, 1998.

quantum non-locality as illustrated most strikingly with the two-slit experiment for photons, but also by EPR entanglement. The localisation of such states is caused by the QSD terms acting non-locally via the macroscopic detectors, which are themselves permanently localised by QSD effects. Process physics is a stochastic non-local hidden variable theory, and so is consistent with the experimentally observed violation of the Bell's inequalities for local hidden variable theories.

Process physics is seen to realise Wheeler's suggested informational '*it from bit*' program via the sequence '*bit* → *gebit* → *qubit* → *it*', but only by modelling Gödelian limitations on informational completeness at the *bit* level. Process Physics is at the same time deeply bio-logical - reality is revealed as a self-organising, evolving and competitive information processing system; at all levels reality has evolved processes for self-replicating information.

Process Physics Resources

1. R.T. Cahill and C.M. Klinger, *Bootstrap Universe from Self-Referential Noise*, gr-qc/9708013.

2. R.T. Cahill and C.M. Klinger, *Self-Referential Noise and the Synthesis of Three-Dimensional Space*, *Gen. Rel. and Grav.* **32**(3), 529 (2000); gr-qc/9812083.

3. R.T. Cahill and C.M. Klinger, *Self-Referential Noise as a Fundamental Aspect of Reality*, Proc. 2nd Int. Conf. on Unsolved Problems of Noise and Fluctuations (UPoN'99), eds. D. Abbott and L. Kish, Adelaide, Australia, 11-15th July 1999, **Vol. 511,** p. 43 (American Institute of Physics, New York, 2000); gr-qc/9905082.

4. M. Chown, *Random Reality*, New Scientist, Feb 26 2000, Vol 165 No 2227, 24-28;

   http://www.newscientist.com/features/features.jsp?id=ns22273

5. C. Gent, *Is Reality a Side-Effect of Randomness?*, Flinders Journal, Vol 11 No 4, 2000; http://adminwww.flinders.edu.au/PRIO/Journal/FJournal2000No4.html

6. R.T. Cahill, C.M. Klinger and K. Kitto, *Process Physics: The Limits of Logic and the Modelling of Reality*; in preparation.

7. Process Physics Web Page:

   http://ph131.ph.flinders.edu.au/html/people/processphysics.html

8. The precursor to process physics was

   R.T. Cahill and C.M. Klinger, *Pregeometric Modelling of the Spacetime Phenomenology*, Phys. Lett. A **223**(313)(1996); p217, Proc. First Australasian Conference on General Relativity and Gravitation, ed. D.L. Wiltshire, Inst. Theor. Physics, University of Adelaide 1996; gr-qc/9605018.