**Digital Foundations for Evolvable Genomic Intelligence and Human Proteanism: Complexity With Novelty Production**

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Abstract

Despite prolific innovations and diversity in economic and biological systems, the theoretical impasse on novelty production has led to a longstanding reliance on randomness or statistical white noise error terms. Extant decision sciences and game theory, respectively, conflate rationality with optimal choice from a prespecified action set and rule out Nash equilibria with strategic innovation or ‘surprises’. In contrast, the Wolfram-Chomsky schema implies that only digital software systems capable of computational universality and Gödel Incompleteness can produce novelty. Till recently how this relates to genomic intelligence which reaches its apogee in general purpose highly protean human intelligence has not been clear. Following Walker-Davis on the ‘algorithmic take-over’ of biology with the digitization of inheritable information in the genome, the epochal Barbara McClintock discovery of viral software based transposable elements that can ‘edit’ the genome, underscores the truism that only software can change software and is instrumental for evolvability and brain plasticity. Key developments with Adaptive Immune System (AIS) and the Mirror Neuron System (MNS), latterly mostly in primate brains, involve distinctive Gödelian features for eukaryote intelligence of self-reference (**Self-Ref**) and offline virtual self-representation (**Self-Rep**) for complex self-other interaction with prodigious open-ended capacity for anticipative malware detection and novelty production within a unique block chain distributed ledger. This is found only in the AIS from the get-go for somatic hypermutations for novel anti-body production and in humans as unbounded proteanism for novel extended phenotypes in the form of artifacts outside of ourselves. Thus, extant decision sciences and Complexity Economics that overlook human proteanism for novelty production may have no basis in the evolution of human intelligence and complexity. Clearly, radical rethinking is needed to navigate the burgeoning digital world.

Keywords: Genomic Intelligence, Immuno-Cognitive Systems, Digital information processing, Self-Reference, Self-Representation, Complexity, Novelty Production, Block Chain Distributed Ledger

1. **Introduction:**

Despite the obvious waves of innovation in economic systems and similar rampant genotype and phenotype diversity in biological systems, there has been a long-standing theoretical impasse on novelty production. The standard model for novelty production in biology and economic systems has had to rely on randomness or statistical white noise error terms. Decision sciences and game theory, for over eight decades, conflate rationality with optimal choice from a prespecified action set with no scope for novelty and also rule out strategic innovation or surprises as Nash equilibria of games (see, Bhatt and Carmerer, 2005).[[2]](#footnote-2) Indeed, in a voluminous book running into 2000 pages on the foundations of Behavioural Economics (Dhami, 2016), which investigates at length behaviours relating to trust, cooperation and defection strategies in standard game theory, there is no mention of how agents ‘think outside the box’, pursue creative behaviours, such as strategic innovation or arms races in novelty. Further, as noted in Markose (2021b), Complexity Economics (see, Holt et. al. (2011), Colander et.al. (2000)) which purports to address shortcomings of mainstream Economics, for most part ignores novelty production and ‘surprises’, as in radical disruption of structures and uncertainty of outcomes that exceed a known set of outcomes, as being significant to complex phenomena.[[3]](#footnote-3)

 At the margins of mainstream Economics, there has been a long legacy of economists following the Schumpeter (1934,1941) evolutionary tradition (see, Hanush and Pyka (2007) for recent contributions of this group). They underscore how the “perennial gale of creative destruction” in capitalism during which new products and processes dislodge old ones, is a far more potent force than optimization within extant set of technologies as espoused by the Neoclassical model of efficiency with price competition among existing firms and products (see, Witt (2008), Day (1984, 2007)), and Baumol (2002, 2004)). Day (1984) discusses how the stationary economic equilibrium is necessarily disrupted by the “most human quality, namely, the ability of individuals to conceive new combinations and of groups to form unanticipated solutions to temporarily unresolved conflicts… . The existence of entrepreneurs must no doubt be explained by the forces of biological and social evolution that explain human development generally. Certainly, it is related to the emergence of creative intelligence.” In turn, Baumol (*ibid)*, in keeping with the Schumpeter (1934) vision of ‘creative destruction’, has extensively discussed and documented the role of the relentless Red Queen[[4]](#footnote-4) type strategic arms race in innovation by firms of products and processes in capitalism, which he claims is not addressed in mainstream economics.
 Recently, the Nobel prize winning economist Romer (2016) has critiqued the multitude of exogenous random shocks that typically model ‘surprise’ or innovation in the mainstream macro-economic framework. Romer (*ibid* ) has compared the model of white noise shocks to the discredited phlogiston theory of fire. Romer (2016) states : “Macroeconomists got comfortable with the idea that fluctuations in macroeconomic aggregates are caused by imaginary shocks*, instead of actions that people take* (italics added) .” Similar considerations have led Witt (2008) to conclude that “the emergence of novelty is a driving agent in evolution.... and ...the backbone of (economic) development and growth. Despite its central importance, the emergence of novelty is largely a blind spot in economic theory”. As a notable member of the Austrian School, Schumpeter (1934, 1941) has had an enduring influence in placing innovative disruptive forces at the centre of economic phenomena. However, it is Hayek (1967, 1952) who is perhaps the first economist to refer to the Gödel (1931) epistemic challenges of cognitive incompleteness and its necessity for complex phenomena.

 It is interesting to note that a leading neuroscientist Karl Friston (see, Friston (2010), Friston et. al (2013)) who relies on the Free Energy Principle and the thesis of general intelligence as a means of maintaining homeostasis of life by minimizing the dissipative forces of entropy and disorder, which is not without its problems (see, Colombo and Pallacios (2021)), does not fall into the trap of mainstream optimization framework of decision making where search for optimal choice is restricted to what is already known. Schwartenbeck et. al (2013) state that search for novel solutions and “explorative behaviour is not just in accordance with the principle of free energy minimization but is in fact mandated by it”. However, from what follows, it seems that there has been insufficient discussion on the problem of maintaining homeostasis of life’s vital signs within feasible physical/analogue states, viz. minimizing surprisals, when the latter is under the aegis of smart or algorithmic controls and must contend with biotic malware or adversarial agents.

 In the context of modelling rational players in game theory, Binmore (1987) seminally upped the stakes on the flawed premise of constraining rationality to operate within a closed and complete logical system. Binmore (*Ibid*) raised the ‘spectre of Gödel (1931)’ on how determinism and predictability of equilibria with a prespecified action set, which preclude novel actions outside of this set, could fall foul of Gödel’s Liar. The latter is the agent which represents the formal operation of negation and falsification to what can be computed/predicted and in diverse settings becomes the model of an adversarial agent whose actions *a priori* cannot be constrained in any way. In software based digital systems the outputs of executable code of algorithms as in molecular biology and the digital economy epitomizes determinism of computation. In such systems, the adversarial agent in the form of viral software, which is coextensive with life itself (Markose 2021a), is axiomatic as the negation operator. In the first instance at the level of molecular biology, as will be shown, this forces genomic information processing to adopt the cognitive framework of Gödel Incompleteness that permits endogenous exit from listable sets, to avoid the irrational state of logical inconsistency and to access an open-ended search for novel biotic malware and to respond likewise with novel strategies.
 Economists have long been alerted to the Gödel Logic of adversarial agents involved in the guise of rule breaking agents who will ‘negate what they can predict’ in the so called Lucas policy ineffectiveness thesis, Lucas (1972, 1976). Goodhart’s Law (1981) underscores the demise of formalistic policy targets from actions taken by highly protean regulatees who will game the system. However, as will be seen the use of statistical white noise terms to model novel actions or ‘surprises’ in Economics or worse still that ‘rationality’ requires restricting choice of actions from what is already known in order to minimize deviations from a quantitative target, vitiating the search for novel adversarial actions, has led to disasters in policy design where regulatees are effectively viewed not to break rules and innovate. Indeed, it is my exposure to Binmore’s 1987 Gödelian critique of game theory and the Lucas critique on the necessity of ‘surprise’ strategy against agents who can negate what they can predict that led to the discovery of the logical conditions for a Nash equilibrium of a game with novelty production (Markose, 2017). [[5]](#footnote-5)
 In contrast with models of statistical randomness as drivers for change, there has been a longstanding legacy of the Wolfram-Chomsky schema (Casti (1994), Albin (1988), Markose (2004, 2005, 2017) on the *sine qua non* of novelty production in complex adaptive systems that can manifest as Type IV undecidable structure changing dynamics with novel objects taking a syntactic or constructive software form associated within digital systems capable of Gödel incompleteness.[[6]](#footnote-6) However, it is not till Prokopenko et. al. (2019)[[7]](#footnote-7), and specifically with Markose (2017, 2021a,b) that evidence has been given for how advanced eukaryote genomic intelligence evolved the four distinctive Gödelian aspects of digital information processing that permit open-ended novelty production. The first of these, as found in the burgeoning digital economy is the role of unique identifiers. This takes the form of bio-peptide identifiers in biology and more generally can be understood to be Gödel numbers for encoded information. The other two characteristics are the self-referential (**Self-Ref**) and offline virtual self-representational (**Self-Rep**) mirror platforms, using epithets taken from Hofstadter (1999). The break through on the significance on these staples of Recursive Function Theory[[8]](#footnote-8) found in textbooks on the subject such as Rogers (1967) and Cutland (1980), starts with the insight of Gershenfeld (2014, 2017 Chapter 3 p. 109) that the self-referential operator (aka Diagonal operator) where a program *m* builds the machine that runs program *m* corresponds to the self-assembly programs associated with the ribosome and other transcriptase machinery involved in gene expression for the somatic morphology and regulatory control of the organism (see, Tibbits (2012)). The next breakthrough (Markose, 2017, 2021a) is to acknowledge that halting self-assembly gene codes that create the organism are theorems of the genomic system and information processing follows that of formal systems (Smullyan, 1961) governed by the principle of logical consistency.
 The relevance of Recursion Function Theory for genomic information processing follows from the Walker-Davis (2013) premise on the ‘algorithmic take-over’ of biology with the digitization of inheritable information in the genome and the epochal Barbara McClintock (1984) Nobel prize winning discovery of viral software based transposable elements that can ‘edit’ the genome by scissor paste (transposons) and copy paste (retrotransposons). This underscores the truism that primarily only software can change software, rather than random transcription errors. Federoff (2012) states “It is becoming increasingly difficult to escape the conclusion that eukaryotic genome evolution is driven from *within* (italics added) by the stronger winds (with perhaps occasional gale force gusts) of transposon activity.” Transposable elements have been found to be instrumental for evolvability and brain plasticity on one hand and malign internal hacking on the other.
 Key evolutionary developments with Adaptive Immune System (AIS) 500 mya and the Mirror Neuron System (MNS), latterly mostly in primate brains, respectively, demonstrate virtual offline mirrored self-representation (**Self-Rep**) of the expressed genomic self-assembly codes for complex self-other interaction in the AIS and reuse of codes of self-actions from the sensory-motor cortex for social cognition and inference regarding conspecifics in the MNS (Gallese (2009), Gallese and Sinigaglia (2011)). Prominently, in the context of biology and software systems, as noted by Markose (2017, 2021a) in her development of digital adversarial Gödel-Turing-Post (G-T-P) games, while digital systems have powerful benign capabilities for replication leading to digital copies of high fidelity at low cost and also ease of recursive recombination, the Achilles heel is that such systems can be hacked by Gödel’s Liar in form of internal (transposable elements) and external viral software or by deceit and negation in human and primate behaviours. This has far reaching consequences in the evolution of intelligence, which reaches its apogee in general purpose highly protean human intelligence.
 The main objective of this paper is to underscore the significance of the above adversarial digital game as being central to the evolution of a unique Gödelian self-referential framework of genomic intelligence in advanced multi-cellular life with an astronomic capacity for open-ended search for novelty being built in from get-go. Indeed, viral software based Recombination Activation Genes (RAG1 and RAG2) were first associated with diversity in T-cell receptors of the AIS ( Kapitonov and Jurka, 2005) with prodigious open-ended capacity for anticipative malware detection to identify virtually any foreign pathogen self-referentially as software deviations from of self-codes. Further, advances in gene science and molecular biology in the post McClintock era and new thinking in digital information processing in terms of the 21 st century nomenclature on block chain distributed ledger are needed to fully understand the significance of novelty production being possible only in advanced software systems capable of Type IV dynamics in the Wolfram-Chomsky schema. This facility found only in the Adaptive Immune System and the human brain runs into orders of magnitude of 1020 – 1030 that exceed the pre-scripted germline genome size many times over. From the perspective of designs for robust policy and sustainable software systems, which includes life itself, what is significant and often overlooked is that in order to achieve objectives along one-dimension, commensurate complexity in regulatory framework has to be achieved to keep internal and external Gödel Liar style adversarial agents in check. The latter is often feasible only by non-ergodic co-evolutionary arms races in novelty when adversaries co-exist. The main message here is that it is this adversarial game in the evolution of advanced multi-cellular life necessary for the primacy of gene codes that has led to the epitome of self-referential social cognition in humans for complex self-other interaction and for open-ended adaptive novelty production.
 Three sources of syntactic or software-based novelty production can be identified. Novelty that can be inheritable via biological evolution has to be ‘retrotransposed’ into the germline, the molecular mechanics of the stringent conditions for selection for additions of novel blocks of biotic codes within a genomic block chain are yet to be understood. In terms of learned novel behaviours in the lifetime of organisms, this is found only in the Adaptive Immune System for somatic hypermutations for novel anti-body production and in humans as unbounded proteanism for novel extended phenotypes, to use a Dawkins (1987) term, in the form of artifacts outside of ourselves. What is important to note here is how AIS, which predates the MNS by millions of years, from the get-go is geared toward the anticipative horizon scanning for novel non-self antigens and to respond with novel antibodies that lie *outside* of known listable sets.
 This paper provides a critique of extant decision sciences and game theory which overlook human proteanism by restricting optimal choice within what is already known may have no basis in how genomic intelligence evolved. In what follows, a novel syntactic virtual object entailing instructions that can also be realized as novel extended phenotypes of humans, is rigorously defined as one that cannot belong to (recursively) listable sets and hence novel human actions and artifacts are the only source of Type IV complex undecidable structure changing (non-ergodic) dynamics in socio-economic systems. At these points, no finite meta model exists for prediction, marking the radical uncertainty that some have tried to investigate (see, Kay and King (2021)) albeit without adequate tools needed for Gödel Incompleteness with novel events that cannot be algorithmically listed.
 Section 2 of the paper will start with the pitfalls of modelling novelty and strategic innovation as random white noise terms. A brief review based on Markose (2021b) shows that economists need to revisit this problem well-known from the economic critiques of Lucas (1972,1976) and Goodhart’s Law that have a close bearing on Gödel Logic and the implications of formalistic rules that suffer ‘negation’ by adversarial regulatees can lead to policy and systemic failure. Indeed, few have noted that it was Lucas (1972) who first floated the idea of the necessity of a surprise strategy when policy is rendered ineffective by agents who negate what they can predict as in the Binmore (1987) adversarial game. With the scientifically flawed models for statistical noise terms for novelty and surprises having dominated Economics, this blind spot in economic models on human proteanism, which often takes the form of actions of adversarial rule breaking regulatees, led to disastrous policy consequences, especially with the 2008 Great Financial Crisis in Western economies (see, Haldane (2012), Eichengreen (2010), Jones (2001), Goodhart (1994, 1981)). Likewise, being wedded to a pre McClintock era of gene science, biology has arguably suffered from this blind spot on novelty production and does not have the wherewithal beyond random shocks to explain what Richard Day (1984) has called “the emergence of creative intelligence” a matter that belongs to the purview of “the forces of biological evolution”. This section also discusses why far more Recursion Function Theory than has been used to date is needed to incorporate the advances in gene science in the post McClintock era into a model of genomic intelligence with prodigious capacity for novelty production that is stringently processed by a unique block chain distributed ledger.
 Section 3 is a technical section which starts with the antecedents of the notion of self-reference and Gödel Incompleteness results. These lie with the Cantor Diagonal Lemma and the so called ***Diag (.)*** operator for self-reference, which sets in motion the steps needed to exit from listable sets for novelty production. What many consider to be disparate structures of the self-referential and self-representational mappings in mirror platforms of the embodied self in the Thymus of Adaptive Immune System and in Mirror Neuron Systems of humans are shown to be part of an identical set of recursive function operations that permit open ended search for adaptive novelty. In particular, this section will outline how Gödel sentences, far from being an esoteric construction, are ubiquitous in genomic information processing and can be seen to be a hashing algorithm in the 21 century nomenclature, which permits a self-code to self report it is under attack. The construction using the Rogers Fixed Point Theorem (Rogers (1967)) to the detect hacking by novel non-self antigens by the Adaptive Immune System has two parts to the fixed point. The first part of the fixed point constructed offline in the Thymic T-Cell receptors in an anticipative way has to ‘sync’ with the other part which arises experientially and gets recorded in the peripheral MHCI receptor in real time if and when the said non-self antigen attacks the peripheral tissue emanating from the expression of the tissue specific gene code.However, the very large literature on non-self antigen detection by the AIS does not model the problem as one of identifying the fixed point of a (negator) software function that involves a unique hashing algorithm.
 The concluding Section 4 of the paper will discuss how targets and objectives could run into Goodhart’s Law style destabilizing outcomes when they are hitched up to the recursive powers of recombination in digital systems. The latter adduced to be a hall mark of novelty production
(Bienhocker (2011)) and is recognized to be a factor in AI driven burgeoning digital economy ([Brynjolfsson,](https://library.villanova.edu/Find/Author/Home?author=Brynjolfsson%2C+Erik%2C) and [McAfee (2014)](https://library.villanova.edu/Find/Author/Home?author=McAfee%2C+Andrew%2C)), when divorced from block chain distributed ledger style software technologies, can run amok. In contrast, the fact that original building blocks of life have remained intact and immutable and not succumbed to the ravages of protean malware agents for over 3.5 billion years is the phenomenal success of the unique eukaryote genomic intelligence that has evolved.

**Section 2 Why We Need Digital Models for Novelty Production**

***2.1 Pitfalls of Modelling Novelty and Innovation as White Noise Prediction Errors***

In all variants of statistical models of uncertainty, regardless of the domain of modelling (see, Barto et. al (2013)), a novelty or surprise is a statistical noise term, typically modelling as a prediction error. There has been little consideration of novelty as syntactic objects or new actions (extended phenotype) that lie outside of recursively enumerable/listable sets as in the case of Gödel undecidable propositions (Prokopenko et. al. (2019)). Hence, these terms will be qualified as novel actions or surprise strategies if deliberate novel actions of agents are involved in the creation of endogenous structure changes and uncertainty. This is to avoid confusion with the case of prediction errors or noise in communication channels. In the case of a forecasting model, it is the prediction error that marks the difference between the actual realized values of random variables and the expected/forecast values for the same by an agent’s model. In control theory where the state variable can be impacted by agent’s actions, the surprise is the difference between the target and the policy-controlled state variable mostly done under the assumption that it is a game against nature and hence optimality typically implies that the only deviations from the target are brought about by white noise terms.
 The Theil-Tinbergen Linear Quadratic Gaussian models have been the dominant model for policy design in macro-economics (see, Hughes Hallett (1989)). The objective function takes a quadratic form where the policy maker minimizes the squared deviations of the state variable from a stated quantitative target vis-à-vis it using a policy variable and the only stochasticity comes from a Gaussian white noise term with mean zero and an exogenously given volatility.
 Nevertheless, economists have long been familiar with the scenario in which the first Lucasian (1972) postulate called policy ineffectiveness asserts that policy that can be predicted or rationally expected can be negated by contrarian or adversarial agents in the private sector. In other words, what may be deemed to be ‘optimal’ may no longer be the case if this policy is announced to the public. In the face of the vulnerability of predictable or preannounced policy from contrarian regulatees who ‘negate’ it, in the second postulate, Lucas (1972) had seminally advocated the use of indeterminism and a surprise policy strategy in order to achieve policy objectives. However, given the state of economic modelling this took the form of a white noise prediction error in the form of surprise inflation. [[9]](#footnote-9)
 Till Markose (2017) there has been no precedent of a Nash equilibrium of a game in which novel/surprise strategies become the only logical and strategic outcome against the Gödel Liar like rule breaking agent with players having to exit from extant action sets. Hence, except for Goodhart (1994, 1981), economists misunderstood the Lucas surprise strategy (modelled as a prediction error for inflation forecasts) and sought to reinstate determinism in policy by having the authorities pre-commit to a fixed rule. There was scant acknowledgement of the first Lucasian postulate and of Goodhart’s Law (1981) that there are serious threats to preannounced objectives and targets of policy from protean rule breaking regulatees who use innovative instruments for this, euphemistically called regulatory arbitrage[[10]](#footnote-10). As ‘surprise’ inflation seems both bizarre and bad, a large bandwagon formed around a literature, reviewed by Markose (2020b) and critiqued by Goodhart (1994), which recommended that authorities remove inflation surprise and pre-commit to fixed rules. This led to policy disasters first with the currency peg used as an inflation anchor. George Soros (1995) has shown familiarity with the Liar Strategy in implementing the contrarian short position he took against the Bank of England in 1992 and won over $1 billion of central bank reserves used in the defence of the Pound Sterling. A roll call of leading macro-economists urged central banks to show resolve and transparently defend the currency pegs, every one of which was destroyed by short selling currency speculators.[[11]](#footnote-11) Having had to abandon currency pegs, from 1994 authorities have tried to control the monetary environment by using further formalistic rules regarding inflation targets and for financial and banking regulation, again whilst oblivious to protean rule breaking.
 Goodhart (1994) in his ‘Game Theory for Central Bankers: Have they got it right ?’ challenged the view that somehow the first postulate of Lucas applies differentially to the real side of the economy (viz. failure of policy from being preannounced) but this is purported not to apply to the nominal side while targeting inflation. The exclusive focus on minimizing inflation from its target became the mantra of central banks since. Authorities effectively adopted a Theil-Tinbergen style rule regarding the interest rate as the policy variable.[[12]](#footnote-12) Central banks abandoned any attempt to monitor the consequences of structural changes with the Phillips Curve having become flat and permitting prolonged low interest rates in the form of the so called Greenspan Put and the subsequent out of control asset bubbles (Markose (2013)). That the only Nash equilibria of such adversarial games if rule breaker/Liar cannot be eliminated, is a coevolution by policy makers in an arms race with regulatees or the abandonment of the formalistic rule, was never considered (see, Markose 2017 and 2020b).
 This blind spot in economic models on human proteanism led to disastrous policy consequences with the 2008 Great Financial Crisis in Western economies. A formalistic policy for the regulation of capital in the financial and banking sector that was pursued was the Credit Risk Transfer rule. This permitted banks to reduce capital from 8% to 1.6% by using a risk weight stipulated by the regulator of 20% on buying credit default swaps from AAA rated credit risk guarantors. The latter like American Insurance Group (AIG) soon fell foul of Goodhart’s Law losing their AAA rating as they took on CDS guarantees of over $1 Trillion, which they were unable to service and thereby triggering a financial collapse and tax payor bail out of unprecedented scope. Remarkably, in the design of regulation outside of the macro-economics, little mention is made of Goodhart’s Law or of Lucas postulates on why policy fails due to the adversarial games with agents who have uber intelligence. Generally, about the events leading to the 2007 crisis, Jones (2000) noted a lack of interest by academic economists and regulators to study the widespread undermining of bank capital regulation entailed in securitization and other financial innovations in the $12 Trillion shadow banking (Haldane (2012)). Jones (2000) said “absent measures to reduce incentives or opportunities for regulatory capital arbitrage over time such developments could undermine the usefulness of formal capital requirement as prudential policy tools”. In the absence of simulation models in the tool kits of most economists, Jones (2000) concluded that it was a lack of data for econometric modelling that prevented academic or regulators from keeping track of activities that undermined stated policy objectives in the Basel II banking regulation.
 Finally, the notion of Gödel undecidable dynamics can be identified with the Lucas Critique whereby Lucas (1976) in a third postulate had seminally raised the problem of a lack of structural invariance of the state variables of the economy in the face of novel strategic behavioural responses to anticipated policy events that may cause predictive failure in econometric models for purposes of policy evaluation.[[13]](#footnote-13) The following **Table 1** provides the comparison between three postulates involved in the Lucas policy ineffectiveness thesis, Lucas (1972) and the Lucas Critique (1976), and the equivalent ones in Gödel Logic involving Gödel’s Liar and **G-T-P** adversarial games.

**Table 1 Lucas (1972, 1976) Postulates on Strategic Surprise and Gödel Logic on Adversarial Games With Novelty Based Structure Changes**

|  |  |
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| **Lucas Postulates on Policy Design**  |  **Postulates of** **Gödel Logic**  |
| (1)Regulatees who negate and render ineffective what they can predict is called policy neutrality, or policy ineffectiveness, Lucas (1972). | (1#) Gödel’s Liar will negate or falsify what is computable/predictable; Liar wins only because host has not acknowleged identity of Liar, viz. out of equlibrium, see equation (12.a) |
| (2) Lucas (1972) correctly said, the authorities have to come with a surprise or a novel strategy as known strategies will be negated.Except, Lucas couched the surprise as a white noise prediction error for inflation,  :y= y\* + b( -  e ) +  See, footnote 8.  | (2#)Markose (2017) Nash equilibrium of game where Liar cannot be eliminated is to produce novel strategies, as syntactic objects, outside of prespecified action sets often in an arms race structure. |
| (3) **Lucas (1976)Critique** No econometric model can identify innovation based structure changes that follow from regulatory arbitrage  | (3#) This results in **Type IV undecidable innovation based structure changing dynamics** that no finite meta model can determine the outcome of game at this point.  |
| (4) Due to the bizarre nature of inflation surprise in (2) above, macro-economists made a **grave error of logic**. Instead of recognizing why policy fails due to adversarial agents and the significance of strategic novelty, economists continue to proxy the latter as noise and prediction error, withdrew from the co-evolutionary arms race with regulatees who are left free to ‘arbitrage’ policy on horizon scanning for threats.  | (4#) Genomic intelligence which has to deal with this adversarial game first encountered in the Adaptive Immune System, goes for astronomic openended horizon scanning to protect self gene codes and is prepared to go in for co-evolutionary arms race in novel anti-bodies. Similarly, the Machiavellian human brain that is primed in the art of deceit and in responding to adversaries  |

 Some have recognized the nature of the problem that the private sector may have conflicting objectives to the policy maker ( Acocella et. al. (2012)) and how their responses, which can be novel and adversarial, may make it problematic for the application of the Theil-Tinbergen style control theory due to radical uncertainty and self-reflexive outcomes that are deleterious to policy objectives (Kay and King, pp 346-349). However, economists and decision theorists have persisted in defining ‘optimal’ policy as one that minimizes mean square white noise prediction errors while having no means of simulating, monitoring and responding to novel activities of the private sector that change structures and undermine stated policy objectives. What will be shown in the Gödel style adversarial game in evolution that has moulded genomic intelligence is that in order to maintain homeostasis in terms of desired objectives on the one hand, a framework of open-ended search for adversarial activity against these objectives has to be developed on the other hand. Authorities need to be prepared to coevolve novel counter responses if the adversarial agents cannot be eliminated and, in some cases completely abandon the flawed rule before there is systemic collapse. Extant control theory-based optimization models, mostly aimed at achieving specific outcomes, divorce the Gödel adversarial game from the design of robust and sustainable strategies. **Table 1** shows the grave logical and strategic error being made in extant economic policy design in ignoring the Gödel adversarial game.

***2.2 Why We Need To Take Gödel Incompleteness Seriously Without Tipping into Anti-Computationalism***

 A number of factors are adduced to explain the situation why in over 90 years Gödel (1931) Incompleteness results have been of little relevance even in quarters that espouse machine executable code-based systems. The main reason is that Types I-III equation based dynamics in the Wolfram-Chomsky schema is well understood while Type IV system dynamics that arise directly by software operations on software that requires Recursion Function Theory(RFT) is less familiar. Further, far more RFT than has been used to date is needed to show how information processing in the digital genomic systems of advanced eukaryotes take on characteristic Gödel operations of self-reference and to demonstrate how such systems can endogenously generate Gödel Sentences as a hashing algorithm that permits each biotic code to self-report it is under attack. Thus, the phylogenetic origins of the unique self-referential and embodied self-centric nature of cognition in advanced eukaryotes that arose to maintain homeostasis in terms of the primacy of the gene codes against internal and external malware involve text book RFT operations, for example in Rogers ( 1967) and Cutland (1980), can be missed.
 In the Gallistel and King (2010) discussion on the Computational Theory of Mind, a case is made for how the internal workings of cognition utilize symbol processing operations and of the great generative powers of recursion which permit non denumerable infinite number of algorithms each of them capable of halting in a finite number of steps. This is the class of total computable functions that best describe technologies (Markose (2017), see also Figure 2 in Section 3). As in Gallistel and King (2010), there is growing evidence for the full Gödelization of biology in terms of unique identifiers even to the extent of biotic Zip codes first discovered by the 1999 Nobel prize winner Gunter Blobel . However, there are major omissions in CTM of Gallistel and King ( 2010) on self-reference and self-representational mirror style recursive function mappings, which are staples of a Gödel framework of digital information processing. Without these key steps found in evolutionary structures of Adaptive Immune System and the human Mirror Neuron System, there is no way that such genomic systems can endogenously generate Gödel Sentences, which exit from known listable sets of ‘technologies’.and access novelty. Hence, much of this literature on Computational Theory of Mind has resulted in unedifying skirmishes that lead some authors to hold anti-machine views on how Gödel’s Incompleteness theorems show that “the human mind outstrips the capacities of any Turing machine” (see, Rescorla, 2020).[[14]](#footnote-14)
 As the original Gödel (1931) framework predates the full development of Recursive Function Theory and there is no explicit construction of syntactic objects that lie outside two disjoint recursively enumerable sets, respectively of theorems and known non-theorems, of Emil Post (1944), the Gödel Sentence appears as a funky, esoteric construction of a proposition that asserts its own undecidability that it is neither provable or disprovable. [[15]](#footnote-15)
 The graphics in **Figure 1**, are useful to show an identical recursive function machinery based on **G-T-P** condition of **Self-Rep** from Rogers (1967) which maps from the online to the offline domains. The offline embodied simulations permit meta-inference on self and the other, respectively for the Adaptive Immune System (**Figure 1** **Panel A)** and for the cognitive mirror neuron system (**Figure 1** **Panel B**). Technical details on this are given in Section 3.
 In what marks the start of the vertebrate and mammalian radiation there was a step change in genomic intelligence with the so called Big Bang of Immunology (Janeway et. al (2005)) with the evolution of the Adaptive Immune System (AIS) in the lineage of jawed fish some 500 mya. Analog defences of the innate immune system which include setting up barriers, toxicity, raising temperature by inflammation and ingestion by phagocytes was enhanced with a code-centric bio cybersecurity of stupendous capabilities for complex self-other interactions where the *other* is a self-referential projection of self. In the context of the Adaptive Immune System, **in Figure 1 Panel A** we see an illustration of what has been called the ‘Thymic self’ (Ramon and Faure (2019)) and as ‘the science of self’ (Greenen (2021)). **Figure 1 Panel A LHS** is an offline virtual self-representation (Self-Rep) mapping onto MHC1 receptors of the Thymus Medulla of over 85% of the gene codes of humans (Danan-Gotthold et. al. 2016, Kyewski and Klein 2006 ) which are expressed in halting self-assembly programs for human physiology given on the **RHS of Figure 1 Panel A** . The **Self-Ref** aka Diagonal operator ***Diag (.)***, modelled in the post Church-Turing thesis (Kleene (1967)) era when an algorithm or an effective procedure is deemed equivalent to a machine executable program, specifies that a program *m* of a machine instructs the machine to run *m*. For the latter, Markose (2021a) uses the Gerschenfeld (2012) insight that Self-Ref /***Diag (.)*** operators are programs for self-assembly of digitized materials redolent of the ribosomal machinery of gene expression, shown in **Figure 1 Panel A RHS**,creates the somatic identity of the organism.With the aid of large-scale recombinant recursive machinery called the V-D-J (variable-diversity-joining) based on viral transposon derived Recombination Activating Genes (RAG 1 and.

**Figure 1: Gödel Meta-representation(Rogers,1967) and Mirror Systems in Immuno-Cognitive Systems**Note: ***Offline*** Mirror Systems in Medulla Thymus (**Panel A, Left**) and ***Offline*** Cognitive Mirror Neuron System (**Panel B, Left** ) and respective Bijective Map of ***Online*** Gene Transcription (**Panel A, Right**) and ***Online*** Action Execution in Motor–Sensory Cortex (**Panel B Right**)

|  |  |
| --- | --- |
| ***Offline Recording/Simulation*** ***Equation (8) (LHS) Self-RepNotation***  | ***Online Machine Execution Right Equation (8) (RHS) Self-RefNotation:***   |
| **Panel A (Left)Medullary Thymus Epithelial cells (**m**-TECs) Mirror Mapping** of tissue specific genes/peptides of ~85% of genome  | **Panel A (Right)Baseline Machine Execution of Coding and nc-Genes modelled as a self-assembly of digitized biotic elements of gene codes in set G**(see, equation (1.a))  |
| Baseline : With no malware (g,g)g1, g2, g3,...... gnTheorems of genomic system  | Ribosomal and non-coding Transcription machine executions which halt: *g(g) for all g***G***Related image* |
| **Panel B (Left) Mirror Neurons (Yellow) For Social Cognition: Fires with self action and when self ‘sees’ others’ actions For action prediction with self and other** | **Panel B (Right) Canonical Neurons (Pink on black) Firing Based on Motor Cortex (eg‘self’-walking, Green Arrows)and Sensory/Visual Cortex as observer by self of ‘other’ walking(Blue Arrows)** |
| Discovered by Parma Group ‘90s (Gallese, Fadiga, Rizollatti, Di Pellegrino, Fogassi)(a,a) |  |

 RAG2) , the AIS conducts an open ended search within the T-cell receptors of possible reactive pathogen software to the gene codes, presented in a self-referential way in the Thymic MHC1 receptors, to simulate putative attacks or changes to the gene codes. Flanik and Kasahara (2009} refer to the “an anticipatory system of defence” in the AIS machinery with RAG enabled somatic hypermutations in the T-cells and B-Cells of prodigious capacity which rivals that of the neuronal system. Muller et. al. (2018) state that the capacity of the AIS for “somatic generation of immune recognition motifs of a system (is) of practically unlimited (open-ended) information capacity”.
 The literature shows even more elaborate description of mirroring of online motor and sensory cortex activity[[16]](#footnote-16) , **Figure 1 Panel B RHS**, with the discovery of the mirror neuron system (MNS) by the Parma Group in the 1980’s. Gallesse (2009), Gallese and Sinigaglia (2011) have characterized the MNS as a common neuronal platform for conducting *offline embodied simulations* , **Figure 1 Panel B LHS**, for action prediction in the other based on a parallel set of neurons that fire during action execution by one-self. Ramachandran (2000) describes this as follows: “It's as if anytime you want to make a judgement about someone else's movements you have to run a VR (virtual reality) simulation of the corresponding movements in your own brain and without mirror neurons you cannot do this.” In fact, Ramachandran (2000) made pronouncements that have been regarded to verge on hyperbole: “mirror neurons would do for psychology what DNA did for biology by providing a unifying framework and help explain a host of mental abilities that have hitherto remained mysterious and inaccessible to experiments… And that the emergence of a sophisticated mirror neuron system set the stage for the emergence, in early hominids, of a number of uniquely human abilities such as proto-language (facilitated by mapping phonemes on to lip and tongue movements), empathy, 'theory of other minds', and the ability to 'adopt another's point of view'.” Arguably without the **G-T-P** framework, many of Ramachandran’s views may remain mysterious and controversial. Indeed, despite so called computational frameworks for cognitive biology (see, Fitch 2014)[[17]](#footnote-17) , computational neuroscience and Computational Theory of the Mind (Rescorla (2020)), apart from Tsuda (2014), there has been no explicit discussion of the role of the genomic mirror systems and the recursive information processing in **G-T-P** using the **Self-Ref** and Self -Rep operations.
 Tsuda (2014) identifies how neural systems which need to process a self-referential description use the mirror neuron system as in the mathematics of the Gödel’s incompleteness theorem: “When neural systems process a self-referential description, they may first have to make a copy of the object of self-reference and then refer to this copy. This two-stage formulation can be realized mathematically in the proof of Gödel’s incompleteness theorem through the processes of projecting mathematical statements to natural numbers and of referring to meta-mathematical statements by providing mathematical statements about such numbers. The presence of mirror neurons in animal brains or mirror neuron systems in human brains may also be a realization of the above two- stage formulation in brains, because mirror neurons, or mirror-neuron systems, can be activated, not only by behavior in others similar to one’s own behavior, but also by one’s own behavior.” However, Tsuda (2014) does not utilize the mirror system for a model of cognition capable of implementing novelty production.
 Further, it not well known among extant decision theorists, that when the negation operator or ‘inverter’ function is applied to a Gödelian staple of self-reference (**Self-Ref**) or ***Diag (.)*** operator, it becomes a stepping stone for novelty production in the form of the undecidable proposition of Gödel incompleteness, see Prokopenko et. al. (2019)[[18]](#footnote-18). Systems such as the Adaptive Immune System and the Mirror Neuron Systems that manifest **Self-Rep** already have the wherewithal to process Roger (1967) fixed point indexes for total computable functions that can alter extant self-codes.
 Finally, as discussed in Markose (2017, 2021a), it is important to adopt the Post (1944) set theoretic proof of Gödel Incompleteness based on the framework of formal systems and the principle of logical consistency (see also in Smullyan (1961)), for genomic information processing where the halting self-assembly ribosomal style machines that produce somatic identity can be shown to be theorems of the genomic system. This set is disjoint from known non-theorems or what the immunologist Burnett (1958) famously called ‘forbidden codes’ if allowed to run will ‘negate’ the theorems. There is significant mileage to be gained from the use of the Emil Post productive function to construct syntactic objects as Gödel Sentences which involve fixed points of novel negation functions of halting self-codes, with the latter self-reporting they are under attack. Gödel Sentences lie outside all listable sets, viz the two recursively enumerable sets of theorems and known non-theorems of the genomic system and incompleteness is the consequence of logical consistency of the formal system. See **Figure 2** in Section 3. Markose (2017) uses what is called recursive reductions to the same Emil Post productive function that endogenously generates the Gödel Sentence to generate Nash equilibrium novel strategies.
 In the 21 st century, it is widely known that editing of digital documents require software commands of cut/paste and copy/paste. In addition to another ubiquitous command of copy and print, the cyber security threats from internal and external malware agents are all too familiar. The first man-made block chain distributed ledger devised for secure software record keeping is associated circa in 2009 with the Bitcoin (see, Nakamoto (2008)). The paradigm shift in gene science brought about by the McClintock discovery of transposable elements, which account for some 45% of the human genome, clearly highlights that the same processes are at work for editing the digital genomic system as well as for digital documents.
 While not denying that macroscopic environmental and population level pressures of natural selection arising from conspecific or multi-species competition for survival in terms of those which reproduce more and those which die out, there is evidence that at a molecular level of the genome, selective pressures are based on the principles of a block chain distributed ledger. The main principle of a block chain distributed ledger technology is to secure the fidelity of earlier blocks of software so that they cannot be compromised by internal or external malware agents either by hacking or producing new blocks that have outcomes that are antithetical to encoded information in earlier blocks. All nodes of a distributed network should have access to the same information to mitigate intranet gaming due to asymmetric information. Abramov et. al. (2021) and Markose (2021a) are first to observe that DNA based eukaryote genomic systems have the hallmarks of block chain distributed ledgers with the phenomena of the same DNA in all cells of multi-cellular life.
 A remarkable breakthrough in Markose (2017, 2021a) is to show how genomic information processing that follows the Emil Post (1944) set theoretic proof of Gödel Incompleteness based on formal systems organized on the principle of logical consistency (see, Smullyan (1961)) in terms of the set of theorems (the halting self-assembly programs for the somatic and basal phenotypic self-identity) and non-theorems (those antithetical to the former) This permits the generation of Gödel Sentences as in a hashing algorithm for the detection of malware changes and thereby achieve fidelity of record keeping of extant genomic software. As Gödel Sentences cannot be endogenously generated unless that information is recorded in a Post (1944)/Smullyan (1961) set theoretic formal system that is logically consistent, it is the creative and productive set theoretic formulations that can provide the unique principle of block chain distributed ledger technology for advanced multicellular genomic systems that also permit open ended novelty production. The latter is modelled within the Post (1944) productive set. It is becoming clear that in the case of the Adaptive Immune System, biotic malware is flagged out by Gödel Sentences, which lie outside the listable theorems and non-theorems for the organism. This enables biotic elements which may suffer ‘negation’ by a novel non-self antigen to self-report they are under attack. Novel anti-bodies in response to a novel pathogen attack follow only if the relevant Gödel Sentence is generated by the AIS.
 As some of these theoretical developments are very recent, it is fair to say that till recently, it has not been clear as to what the digital **G-T-P** logic has to do with biological evolvability and genomic intelligence which reaches its apogee in humans with their unbounded capacity for novelty production missing in extant decision sciences.
 **Section 3 G-T-P** **Preliminaries on Self-Reference, Diagonal Lemma and Novelty As Exiting from Listable Sets**

The notion of executable machine code in Turing (1936) has had far reaching influence in ushering in the digital age. In contrast, it is astounding that even after 90 years since the publication of Gödel (1931), the key incompleteness result, the steps thereof leading to the Gödel sentence have remained an esoteric construction in the foundations of mathematics of little or no relevance to any observable phenomena. This section will cover the recursion function theory (RFT) on self-referential operations at the heart of genomic digital information processing that can explain and model the evolutionary developments of eukaryote genomic intelligence (GI) first evolved with the Adaptive Immune System and latterly in the Mirror Neuron Systems in primate brains that permits novelty production.

***3.1 Diag (.) Operator and Self-Reference***

 It is well known that the provenance of the notion of self-reference in Gödel (1931) as a stepping stone to Gödel Incompleteness follows from the Cantor Diagonal Lemma proof that a power set of a set has greater cardinality than a set itself.[[19]](#footnote-19) The proof entails a sure-fire way of finding a set that is left out of any enumeration of sets *W1 , W2 …… Wy , ….. ,* given along the rows of a matrix indexed by integers *y* = 1,2,3, … , listed along the columns and their membership of each set *Wx* given as 0 or 1s indicating if an integer belongs to the set in row x , *y* *Wx* or otherwise. In order to identify a set that cannot be in the list *W1 , W2 …… Wx , ….. ,* consider the set along the diagonal. The self-referential predicate s *(x,x) = Diag(x)* follows as it refers to *x Wx* or whether *Wx* contains its own index *x*. On applying a negation operator along the diagonal array, changing 0’s to 1’s and 1’s to 0’s, we now have a set (the anti-diagonal set denoted as *D¬*) that is different from all listed sets *Wx*  by at least one element along the diagonal. The steps given here for the set *D¬*  that cannot belong to any enumeration of sets are informal. Nevertheless, they lay the foundations for Gödel Incompleteness results and await developments with the Church-Turing Thesis (Kleene (1952)) on an algorithm as any intuitive ‘effective’ procedure that coheres with the class of general recursive functions and also the work of Post(1944) on recursively enumerable sets.

 Further, while the self-referential *Diag(.)* operation and the *anti* *Diag(.)* negation operations attributable to malware agents are of great significance in their own right in genomic systems, in mathematical logic they are nevertheless not seen as an end in themselves. They are a means to an end for the endogenous open-ended production of novel syntactic objects that lie outside of listable sets in digital systems that are organized as formal systems governed by the principle of logical consistency (see Smullyan (1961)).

 Where codes, for short, represent the integer g.ns for programs, recursive or computable functions are machine operations on codes by codes. Hence, they are number theoretic functions,
*f :ℵ→ℵ*,where *ℵ* is the set of all integers is the domain and range of these code based computable functions.[[20]](#footnote-20) Such functions have a standard notation (see, Cutland,1980 and Rogers. 1967) that takes the following form with the index or g.n of the program that computes it given as a subscript of the computable function :

 *f(x) y(x) = q* . (1)

That is, the value of a computable function *f(x)* when computed using the program/TM with index *y* on input *x* is equal to an integer *q, y(x) = q*, if *y (x)* is defined or halts (denoted as *y (x)* ) or the function *f(x)* is undefined (~) when *y (x)* does not halt (denoted as *y (x)* ). In terms of Post (1944) recursively enumerable sets, the domain of the function *y*  denoted by Dom *y* or

 ***W****y* = { x | *y(x) ; TMy(x) halts ; x ****W****y }.*  (2)

That is, the membership of the set ***W****y*  can be listed by an algorithm. Note, *y (x)*  is total computable if it halts for all *x *  and it is partial computable if it does not halt for some *x * . In terms of our discussion on the central place given to the self-reference or ***Diag*** operator, we define this as a machine with program *x* which runs *x* as its input, denoted as :

 *Diag(x) = x(x)*. (3)⸦

As already noted, the major insight on what this foundational concept in equation (3) in computation theory means for biology comes from of Gershenfeld (2012) and the MIT Self- Assembly lab (see,Tibbits (2012)). Gershenfeld underscores point that the design framework of programmed 3-D self-assembly of digitized materials in the 21 century fabrication is one that evolution created the protypes of this some 3.5 billion years ago with the self-assembly programs of the ribosomal and other transcriptase machinery. This function *x(x)* is a partial computable function such that for some *x *  it may not halt. Corresponding to this is the archetypical set called the Post (1944) Creative Set

 ***C*** *= { x | x(x) ; TMx(x) halts ; x ****W****x }*. (4)

Set ***C*** that represents the ‘diagonal’ set contains the g.ns of those recursively enumerable sets, ***W****x*,  that contain their own indexes (see Cutland , 1980, 123, Rogers, 1967, 62). In Post set theoretic proof of Gödel Incompleteness, asproof requires halting computation**,** set ***C***can be viewed as all the theorems of the formal system. The complement of ***C****,* represents the ‘ anti-diagonal’ set *D¬* , which is different from ever listable set ***W****x* for all x, viz. it has no index and cannot be enumerated exhaustively:

 ***C¬=*** *{ x | x(x) ↑; TMx(x) does not halt; x ****W****x}*. (5)

Set ***C¬*** has an interesting property of being ‘productive’ in that ***C¬***  contains a recursively enumerable subset ***W****m* ⸦ ***C¬*** such that *m* ** ***W****m* . The code *m* which can be generated as a constructive witness can be added to ***W****m* but cannot belong to **C** *∪* ***W****m* . The index m represents the index for the undecidable proposition and the total computable recursive reductions thereof in relation to index m will generate novel responses, Markose (2017). Smullyan [19,p.58] has noted that the pair of Post (1941) recursively enumerable disjoint sets entailed in the creative and productive sets, play a fundamental role in modern approaches to incompleteness and undecidability. What is significant is that genomic information processing in the immune-cognitive systems naturally fit into this G-T-P formal structures given by sets ***C*** and ***C¬***.

***3.2******Diag(.) Self-Rep Operators and Programmed Self-Assembly Machines in Genomic Systems***

 Using the above system of Gödel numbers (g,ns), integers can uniquely identify gene codes based on the near universal alphabet of the genome. The set of genes codes representing both protein coding and non-coding (n.c) ones is denoted as

 **G = {**g**1** ,g2,...... , g#}. (6.a)

A gene code will be generically denoted as g, and # denotes some finite cardinal number. Note a gene code does not refer to any single gene but a program representing a segment of DNA necessary for the self-assembly of bio-macromolecules. The digital encoding of the finite set of states under which the gene codes are transcribed is denoted by ***S***, with *s****S*** is an element in a finite and countable set of states and other archival information.[[21]](#footnote-21) The set of online action related data from the motor cortex and sensory optical neuronal firings will be denoted by set **A**,

 **A = {**a1, a1, a1, ......, a# }. (6.b)

The firings of neurons arising from self-actions relating to motor activity have been called canonical neurons ( Arbib and Fagg, (1998)). Bulk of these can be regarded to be of a ‘basal’ nature relating to self actions from all motor systems and sensory signals of body schema regarding location and sensations with the neuronal wiring having occurred historically early in neonates or even prenatal.
 In the following, while the narrative is primarily in terms of the tissue specific gene codes in set **G** in (6.a) for the mirror system in the adaptive immune system, as the graphics in **Figure 1** show, on replacing this by set **A** of basal actions in (6.b), we have an identical mirror system for the cognitive mirror neuron system.

***Self-Ref/ Diag Self Assembly Machines:***In order to represent the online self–assembly of the ribosomal RNA or the non protein coding transcription machinery, the following notation from Rogers (1967) is used to represent the online machine execution of the gene code that outputs :

  (7)

Here, the *g(g)* in the subscript of the recursive function  that outputs q underscores the online self-assembly or **Self-Ref** process where *Diag (g)* = *g(g)* such that the gene a program *g* that effectively runs its own code. The output *q* in (2) that follows from the full transcription / translation process produces, respectively, a protein in the case of a coding gene, or a RNA regulatory phenotype based on a non-coding (nc) gene.

 The focus here is on how the recursive function **Self-Rep** mirror operations in the two key genomic neural cognitive and adaptive immune systems take place involving self and other in what is effectively a digital game. The problem of homeostasis in a digital system requires a modus operandi to figure out if self-codes have been changed by a non-self agent. The self-agent will be denoted as the host (h) and the non-self antigen as the parasite (p), with the two protagonists strictly being confined to using total recursive functions as strategy functions. Thus, ‘copies’ of the tissue specific gene codes in the Thymus Medulla epithelial cells (m-**TEC**s) relate to the Gödel meta-mathematics given below in equation (8) that can organize encoded information in off-line domain based on the online ribosomal machine executions of the same. In Markose (2017), an identical recursive machinery is shown to be at work in the cognitive mirror neuron system that records information in a virtual offline setting from the online action related operations in the motor and sensory/optical cortex. This basal digitized information in the respective immuno-cognitive systems will be shown to be ‘theorems’ of the systems and define the objective of the genomic game as one in which hosts have to retain the genomic identity and somatic integrity of the basal codes in terms of the phenotypes or the outputs generated from them.

***Self-Rep Mirror System:***

The famous *offline* Gödel Meta-Representation system in Thymus Medulla can be given the following textbook format from Rogers (1967, p. 202-204 ) and is illustrated in **Figure 1**:

  iff *g(g) .* (8)

Here, the diagonal operation of **Self-Ref** in (7) when a machine runs its own code and halts, denoted by *g(g)* , is bijectively represented in **Self-Rep** format as in s(g,g) for the genome on the LHS of (3). The LHS function (g,g) modelled along the lines of the Gödel 2- place substitution function (see, *ibid*) has the feature that it names or ‘signifies’ in the off-line recording in the Thymus Medulla epithelial cells, m-**TEC**s, the one-one bijective mapping of the machine execution of the gene codes , viz. when the self-assembly machine executions that halt and proceed to output q, the meta system also faithfully predicts the outcome is q. In Markose (2017), this is taken to be baseline point of the game when the pathogen does not disrupt host gene codes.

 In general, the two place Gödel substitution function (x,y) has place-holders from the perspective of self on status of self and status of non-self vis-à-vis self:
(*status of self*, *status of non-self vis-à-vis self*).

Thus, in the (g,g) notation in (8), in the 1st place from the left, is the record of host’s gene code and an identical g in the 2nd place implies that the host has identified that there has been no alteration of this gene code by the non-self antigen or pathogen, aka Liar. In other words the agency of the other is calibrated self-referentially, viz. in terms of self-codes and their recursive functions. The diagonal elements  (x,x), in general, have great significance in the *offline*  meta system organized in matrix form. As discussed in Markose (2017), only diagonal elements demonstrate Nash equilibria when both status of self and self’s identification of non-self status are in sync, with false beliefs and undetected deceit being ruled out. These will be contrasted with off-diagonal elements (x,y) or (y,x). In general, as one substitutes different values (x,y) for a given state s, the whole space of potential genomic outcomes that can be brought about by recursive functions can be explored. There is an important theorem here (see, Rogers 1967)*[[22]](#footnote-22)*that the *g.ns representing (x,y) in the meta-system can always be obtained whether or not the partial recursive function* *on the right-hand side of (8) which executes programs halts.*

 The significance of this bijective offline recording device of m-**TEC**s for tissue specific genes has led Derbinski et al.(2001) to note that “ m-**TEC**s may indeed represent an immunological homunculus, in that they mirror and anticipate the peripheral self”. Markose (2021a) gives the bio-informatics in terms of the recursive function operations of the **V-D-J** recombinant machinery which enables the adaptive immune system to identify putative attacks on the gene codes,
g***G*** by a self-referential process. Some key elements of this are outlined in the next section as to how the **V-D-J** recursive machinery trains T-cell receptors to identify malware alterations of the basal gene codes.
 In the case of the mirror neuron system and the motor-sensory cortex mappings pertaining to actions, a***A*** in (6.b) denotes a generic action code that belongs to the set of actions ***A*** that cause canonical neurons to fire with action execution by self (self-codes, for short). This is shown in Panel B RHS. This gives immediate and unerring action prediction and inference relating to the other by embodied *offline simulation* of the self-codes as in (8) when *g* is replaced with *a* and discussed further in Markose (2017). This LHS of **Figure 1Panel B** shows the mirror neuron that fires with self-action In particular, I will argue that unless there is an exhaustive listing of basal self-codes as in the genomic m-**TEC**s and in the cognitive mirror system of motor-sensory activity, the anticipation of algorithmic alterations of self-codes by the other, malware detection in the case of m-**TEC**s and intentionality of the other in cognitive systems are not feasible. As noted by Firth (2014), the recordings from the sensory-visual and motor cortex constitute “ a large, complex and ancient set of Bayesian priors (visual, sensory, motor) that constrain inference in any ... brain.” Further, he **G-T-P** mirror mappings of this basal self-action set ***A*** to the MNS provides a common neuronal wiring for conspecifics that imbue them with deeply embodied social cognition and common semantically relevant means of communication.

 The graphics in **Figure 1**, are useful to show an identical recursive machinery based on
**G-T-P** condition of **Self-Rep** in (8) is at work both in the mirror system of the m-**TEC**s of the adaptive immune system (**Panel A**) and for the cognitive mirror neuron system (**Panel B**). There are, ofcourse, interesting differences in the processes by which information on the other is conveyed via visual-sensory cortex to the mirror neuron system when external phenotypes are involved in the set **A** (equation (6.b)) and in the case of peripheral antigen receptors and those antigen receptors in the m-**TECs**. Some details of the latter are given in the next section.

***3.3 Gödel Sentence for Liar Strategy/Malware Detection and Genomic
G-T-P Model for Block Chain Distributed Ledger***

The starting point here is to note that a halting computation is proof by construction. The domain of halting self-referential machines constitutes theorems in equation (7) and (8) , are the codes of Theorems in the genomic immune and cognitive systems, respectively, given by the basal sets g***G*** and a**A**. The sets ***G*** and ***A*** can be shown to be the subset of the archetypal creative set ***C*** see, Cutland, 1980, p.133). The latter is a listable set of all self-referential machine calculations that halt with any x*ℵ* where *ℵ* is the set of integers. Set **C** is central to Post (1944) set theoretic proofs for Gödel incompleteness and **Figure 2** gives what Cutland (1980, p.148) calls the miniature form of the Gödel Incompleteness Theorem, adapted for our case. Thus, in the case of set **G** of gene codes, we have self-halting codes where the downward arrow denotes halting Turing machines (TMs)**:**

 ***G=*** *{ g | g(g) ; TMg(g) halts ; g****W****g , for all g****G****} . (9)*

In some formal systems which are consistent, for every *gi****G****,* a negation symbol on gi, as in gi¬ will suffice to produce a listable set of non-theorems in the system. The latter set denoted as **G●**, is disjoint from the set **G** and in **Figure 2**, **G●** displays the *known* listable set containing ‘forbidden’ and altered malware infected gene codes. A halting machine execution of gi¬ will imply the destruction of specific somatic/tissue of gi***G*** and the phenotype associated with it.

 **G ● =***=* **{***g¬ | g¬ (g ¬) ; TMg¬ (g¬) does not halt ↔g****W****g , g(g)* ***}.*** *(10)*

The listable set **G**● = **is a subset of the set ***C~*** in equation and **Figure 2**) has the property explained in Markose (2017) **Lemma 3,** that its index *n¬* entails a recursive enumeration function *(gn¬)= n¬* such that nth element gn¬ indexed as *n¬* can only be added to the listable set **, but, cannot belong to **.
 **Figure 2** illustrates how the listing in the Thymus Medulla of the self-halting tissue gene codes of the halting ribosomal machinery are identical to the listing of theorems in a formal system. The listing of non-theorems of the system, which are the so called ‘forbidden’ codes following Burnet ( ) description of known non-self antigens. ‘Forbidden’ codes are those that should not be executed online in the genomic system as it will produce outcomes antithetical to the original gene codes or theorems of the genomic system. Hence, the forbidden codes belong to the set of non-halting codes, disjoint from the gene codes or theorems of the system.

 What is important to note is that the list of forbidden gene codes cannot be exhaustively listed in the set **G**● = **. The point being here in the miniature formulation of Gödel incompleteness, is that there will be an altered gene code which is undecidable in the formal system, viz. it is not decidable whether it is a ‘theorem’ or not in the system. With the productive function for set **C~** in Post (1944) being the trivial identity function of the index of the set **, *(gn¬)= n¬* is the Gödel undecidable proposition and this lies outside the listable sets ***G*** and , viz. *n¬∉* ***C*** *∪*  as shown in **Figure 2**. In the next section, I will give details of how malware detection is conducted by the adaptive immune system such that the encoding gn¬ can be derived as the index of the Fixed point for novel non-self antigen.

**Figure 2 Gödel Incompleteness Result in Miniature: An Illustration of Mirror Mapping in Thymus Medulla of Gene Codes that are Theorems in Genomic System**Gödel undecidable proposition gn¬ lies outside the listable sets **G** and , viz. *n¬∉****G****∪*. Note
*n¬=* gn¬ .

**3.2 Malware/ Liar Strategy Function and V-D-J based T-Cell Detection of non-self antigens**

We need to bring in the agency of the pathogen qua hacker who can alter the basal gene codes using software. It is useful to assume that the strategy functions for the host and the parasite
fi ,i**h,p) that can alter the basal information in sets ***G*** and ***A*** are total computable functions such that *g*.ns of fi, i**h,p) are contained in set **ℜ***,*

 ***ℜ****= { m | fi= m ,m is total computable}.* (10)

The set ***ℜ*** of all total computable functions, is not recursively enumerable viz. capable of being listed by an algorithm. The proof of this is standard, see, Cutland (1980, p.127). Representing known members of set ***ℜ*** based on sets **G** and **G●,** collectively denoted as **G\*,** the g.ns in set
***ℜ- G\**** in(11) and shown in **Figure 3** present non-enumerable infinite number of ways for new technologies or phenotypes that can be formed and hence also the potential malware alterations to gene codes. In order for the genomic system to maintain digital homeostasis, from get go from some 500 mya the V(D)J RAG genes unleashed the powers of recursive recombinations via the T-cell receptors first to search in the set ***ℜ- G\**** for novel biotic malware that can attack the self-repped gene codes and then the B-cells to find novel antibodies in response.

 Note, from Markose (2017), the best response Post (1944) productive function is also the surprise strategy function with the superscript exclamation mark ! :
 *fi= fi!=m* , such that *m ∈****ℜ****-****G\****, i**h,p) . (11)

 **Figure 3** **Set *ℜ of ‘technologies’ is not recursively listable*** *: “***Think Outside Box”**  ***A surprise strategy is an innovation*** *fi* ***=*** *fi!* ***=*** *m* *,**m****∈ ℜ*** *-****G****,*



Markose (2017) has proved that the best response surprise strategy function given by the Post (1944) productive function that maps outside extant listable sets into ***ℜ-G\**** is a Nash equilibrium when this is triggered by a fixed point of the recursive function of the negation or Liar or malware strategy *fi¬*, i**h,p), defined in (12.a). Only such mapping of the Post productive function will be accorded with the status of strategic innovations. I will show how the **G-T-P** logic can give a plausible model for how the adaptive immune system of the host using **V-D-J** operations identifies new code centric threats by pathogens and the resulting somatic hyper-mutation (Noia and Neuberger 2007) associated with novel ways of countering antigenic attacks in terms of surprise strategies.

 In order to understand how T-cells that are released into the periphery from the offline environment of the m-**TEC**s are selected and how they can detect malware using the **G-T-P** logic, it is useful to define the Liar Strategy or the non-self malware attack, which occurs online in the periphery. The Liar Strategy or malware *fp*¬ aims to change a tissue specific code of gene self-assembly machine *Diag(g)*= *g (g)* which produces output q and recorded accordingly in the m-**TEC** mirror system as
 σ(g,,g)(s) = q. As the malware *fp*¬ attack occurs in the online peripheral tissue specific code with the code change in gn denoted as gn¬, note the real time offline mirror recording is in the *peripheral* **MHC** (Major histocompatibility complex) antigen receptors.

**The Liar/ Malware Strategy** *fp*¬

= q¬ iff σ(g,,g)(s) = q. (12.a)

Thus, the halting online self-assembly machinery as a result of the malware *fp*¬ in (12.a) is:

 = *fp*¬*Diag (gn)*. (12.b)

In (12.a), the effect of taking the malware altered gene code gn¬ with input gn, is to change the output of self-assembly machine *Diag (g­n)* (on the R.HS of (12.a)) in the following way : on the L.H.S of (7.a) we have = q¬ if and only if σ(g,g)(s) = q. Here, ¬ is the ‘not’ or negation symbol. Thus, the malware *fp*¬ in (12.a) produces the opposite of the host’s desired outcome.

 As noted in Markose (2017) with regard to the Liar strategy, here also the malware/pathogen succeeds only out of equilibrium in (12.a) with the malware *fp*¬ alters the gene code to gn¬ under conditions when the host has not yet updated the second place gn in
 (gn¬ , gn) to reflect self-identification of the agency of the hostile other. On the flip side, from the perspective of pathogen, the success of *fp*¬  requires that the host is deceived. As is well known, the adaptive immune system can take four to seven days to respond to a tissue code specific attack by a pathogen. How is this done ?

 For this the T-cell receptor must also have g.n gn¬ obtained during the training received in the offline m-**TEC** environment and from which the fixed point of the reactive malware software *fp*¬ on the gene code gn is obtained. The details of the G-T-P Bio-Informatics of the T-Cell training with positive and negative selection are omitted here as they are given in Markose (2021a). Partially trained T-cells have signatures like s (gn¬, g) in (12.a) and represent machine halting assembly programs being taken over by the malware program and hence are dangerous if released online as they will accomplish the negation of the tissue specific gene code gand lead to autoimmune disease as shown in (12.a). The main point is that the fully trained T-cell receptors that are released into the periphery have to motifs such as s (gn¬, gn¬) for the fixed point for the novel *fp*¬  attack on gene code g, should this happen. In other words, the host’s immuno-cognitive system must encode the Gödel sentence in (13), which uses the Rogers (1967) Fixed Point Theorem for the T-cell identification of the malware function *fp¬*on the L.H.S of (13) and should the attack *fp¬*take place the peripheral **MHC** antigen receptor for the same should record it as in the R.H.S of (13). Once, the host has ‘synced’ with the malware/Liar strategy
 (gn¬, g) in (12.a,b) , set v to be the g.n of *Diag (gn¬*gn¬, gn¬) *=*. Then, on using the updated version of (12.b) in the 4th equality in (13) below, by construction, v is the fixed point of the malware/Liar function. This yields,

**The Gödel Sentence**:

 =.(13)

The index **gn¬,gn¬) is a very precise self-referential statement of which gene code is under attack and the biotic identity of the pathogen that is attacking it, viz the (*fp¬*, g) pair. Further, by construction, this is not a computable fixed point as it will produce a contradiction,[[23]](#footnote-23)and hence in (13) the output of the game is not predictable. At this juncture, whether the pathogen or host will win is undecidable, once the host has identified the hostile agency of the other. This implies, the Post (1944) productive construction of the set in **Figure 2** follows in that the index for gn¬ will lie outside two listable or recursively enumerable disjoint sets, respectively, for the ‘theorems’ of the system and the known list of ‘non-theorems’.
 In summary, the fixed point in (13) permits the tissue specific gene code of the host to self-report that it is under attack by a non-self antigen (the hostile other), and this plunges the genomic system into a state of radical uncertainty in the form of undecidability. At this point, the adaptive immune system of the host is geared toward countering the malware. For this a new anti-body has to be produced and then applied en masse.[[24]](#footnote-24)The host is compelled by **G-T-P** logic of the Gödel sentence **gn¬, gn¬) to adopt the *only* best response function logically permitted by the **G-T-P** framework, which is the Post (1944) productive recursive surprise function, fh! defined in (11). The latter will exit known listable sets and adopt an innovative anti-body specific to the information in gn¬, viz. in accordance with the tissue specific gene code , gn , and the nature of the malware attack on it.

 It is worth pointing out that this is where extant game theory models that have adopted the computability framework misconstrue the power of the **G-T-P** results.[[25]](#footnote-25) Incompleteness requires a constructive generation of a ‘witness’ for an undecidable proposition (see, Smullyan 1961, Chapter 5),which has to utilize a recursive function for this, viz. a Turing Machine, that can be proven to map outside of all extant recursively enumerable sets (of gene codes for actions/phenotypes) in that system. This is in keeping with the laymen’s intuition about ‘thinking outside the box’, as an innovation cannot be confined within extant action/phenotype sets (see, Markose 2017).

 In Markose (2017, **Lemmas 3** and **5**), it is shown how a non-trivial recursive reduction function from the indexation of the undecidable proposition from the Gödel sentence in (13) given as gn¬ = n¬ in **Figure 2,** will produce a Nash equilibrium novelty producing recursive surprise function fh!. In the case of the adaptive immune system, this takes the form of new antibodies. Corresponding to the set  in **Figure 2** , the ****recursive reduction that implements the surprise strategy function will be indexed as n! such that the surprise strategy set  satisfies the consistency requirements of the basal information in **Figure 2**, viz. n! can only be added to  and cannot belong to **** . This is shown in the structure of a co-evolutionary arm race with innovative antibodies that can ensue as a Nash equilibrium in which both host and pathogen coexist.

 The arms race in the immune system is exactly that- the immune system is primarily evolving its defensive tactics against software hackers, which aim to ‘highjack’ the original gene codes to do their bidding. Genomic identity and conservation of some gene codes, which has continued over the millennia is the remarkable consequence of the immuno-cognitive system being able to put in place a code centric cyber security. The spectacular horizon scanning done by the adaptive immune system and the decentralized nature of biotic cyber defence are other notable features of the system. The block chain distributed ledger principle for the digitally controlled homeostasis for the eukaryote genomic system lies in the fact that the series of Gödel Sentences will get flagged out as surprise or novel malware that have attacked a gene code. In Markose (2021a), it has been conjectured how the gene regulatory networks follow the powerful Post recursive reductions for relays of digital on-off switches that maintain consistency with the archetypical the disjoint recursively enumerable of Theorems and known non-theorems of the genomic system given in **Figure 2**. This accounts for the enduring conservation of the blocks of information of the genome from over 3.5 billion years ago with novel additions which are consistent with extant blocks that are theorems of the genomic system. mitigates inclusion of deleterious biotic malware
 Doyens like Gregory Chaitin (2012, 2013) have underscored the role of code based models as opposed to equation driven ones for evolutionary innovation in his model for ‘Life as Evolving Software’. However, being wedded to the pre McClintock (1984) era of gene science and evolution, the Chaitin metabiology[[26]](#footnote-26) purports that random mutation in software is sole driver of new forms. Hence, Chaitin, despite making the digital basis of DNA central, dispenses with the ingredients of
**G-T-P** to do with **Self-Rep**/**Self-Ref** as being essential to novelty production, incompleteness and evolvability. The prototypes of the key ingredients in genomic evolution are the mirror systems in the Thymus Medulla and the mirror neurons in the brain.

 4**. Conclusion**This paper provides a critique that extant decision sciences and game theory which overlook human proteanism and novelty production by restricting optimal choice within what is already known may have no basis in how eukaryote genomic intelligence evolved. The widespread use of statistical white noise terms to model agent induced endogenous novel phenotypes and strategies are shown to pose serious problems in economics and biology alike. In biology, in the post Barbara McClintock era, evidence that viral software based transposons with scissor/paste and copy/paste functionalities in the context of a digital genome is seen to be the agent for both malign and benign genomic change. Further, the non-self antigen that can hack the genomic code loomed large with multicellular life and a step change in genomic information processing with the development of the Adaptive Immune System occurred some 500 mya and in the Mirror Neuron System in primate brains for complex self-other interaction and novelty production. Till 2014, despite so called Computational Theory of the Mind (see, Rescorla (2021)) nobody apart from the cognitive neuroscientist Ichiro Tsuda (2014) remarked about the relevance of the Gödel (1931) self-referential operations for self-image in *offline* platforms as in human Mirror Neuron Systems. Markose (2017,2021a,b) has adduced evidence from gene science and neuroscience for the immune-cognitive genomic digital information structures that correspond to the recursive function theory of Gödel-Turing-Post.
 Indeed, as first indicated by Binmore (1987) critique of extant game theory, software and formalistic systems which represent determinism is vulnerable to being hacked by viral agents who Binmore calls Gödel’s Liar. This results in the impossibility of restricting the activity of biotic malware software that can alter self-codes of a multi-cellular host to a prespecified set. This underpins the development in the eukaryote Adaptive Immune System of a recursive recombinatorial generative open-ended explosion of exploration for novel digital signatures of non-self antigens that are reactive to self codes. Homeostasis in terms of the primacy of the eukaryote genomic codes which digitally determine autonomy regarding somatic identity and physical vitals in the evolution of eukaryote genomic intelligence has made Gödel sentences a ubiquitous means by which a biotic element of the host self-reports a non-self malign attack on it within a unique block chain distributed ledger. Based on Markose (2017, 2021a,b), the Post (1944) productive function and recursive reductions thereof constitute the workings of the eukaryote genomic distributed ledger which ensures extant blocks of gene codes are not ‘negated’ and any novel additions are consistent with previous blocks with constituent biotic units capable of self-reporting violations. Phenomenal as the self-related activities of locomotion, vision and other sensory faculties are with organisms which are encoded in genomic blocks and hardwired in expressed morphology (see, Zadeh (2020)), the strong premise here is that evolutionary advances in eukaryote immuno-cognitive systems which reaches its apogee in humans is related to social cognition for complex self-other interactions and novelty production. This arises in what Markose (2020a,b) called **G-T-P** digital games with the other in the form in co-evolutionary arms races of somatic hypermutations and extended phenotypes. The price for such open ended and anticipative self-referential search for fixed point projections for novel actions of the other is autoimmune disease and neuropsychiatric disorders like autism and schizophrenia relating to the self-other nexus. The remarkable aspect of the genomic block chain distributed ledger technology shown in **Figure 2** is that the open-ended access to novelty is achieved within a framework of formal consistency and with no explicit objective function except for the implied ‘Theorem-hood’ of genomic blocks that determine the somatic self whether in the Thymus or in the brain.
 This brings us to the problems of targets and objectives which can be gamed by protean agents as famously stated in Goodharts Law[[27]](#footnote-27). As discussed in Markose (2020b) and extensively covered in the credo of Classical Liberalism from Kant (1965) and Hayek (1969,1975) on the necessity of end-neutral rules of state coercion is to avoid predetermined outcomes or targets. These may appear well intentioned and expedient but can interfere with autonomy of actions of highly protean individuals.
 The biotic system is regulated in a rigorous way in which Liar like threats are identified by wide-spread simulations and offline horizon scanning in the adaptive immune system. Where the Liar/pathogen cannot be eliminated, the biotic system shows the capacity for innovation based co-evolutionary arms race with the hostile agent. This arms race is a Nash equilibrium in which neither party can unilaterally withdraw without facing destruction of their objectives. However, as I have already noted, as extant game theory is silent about ubiquitous activities like these; this is also missing in any discussion about policy design in mainstream economics.
 Externally set targets could give perverse incentives that can lead to system failure along the ‘futility, perversity, jeopardy’ lines of Hirschman (1971) or lead to dead ends of local optima[[28]](#footnote-28) (see, Lehman and Stanley (2011)). The target or reward can elicit two left shoes as in the Soviet Gosplan style quantified targets, and when adaptive capabilities are given as in the Bostrom (2014) protean paper clip robot it can inventively smelt down all metal can follow. The blind spot on novelty production and human proteanism responding perversely to regulations based on the flawed foundations of mainstream economics was contributory to the 2009 Great Financial Crises that almost brought down entire Western banking systems. This does not bode well for the burgeoning digital economy (see Buckmann et. al. 2021). The ancient precedent found in eukaryote digital management of homeostasis in a unique block chain distributed ledger, as set out in this paper, provides valuable insights for sustainable regulatory frameworks.
 We are fast transiting to an increasingly digital socio-economic world of computer software driven Artificial Intelligence (AI), robots and Internet of Things. In context of the 4th Machine age, Brynjolfsson and McAfee (2014) have highlighted the significance of digitization to lie with information packaged in discrete programs with the ease of making digital copies, viz. replication, with extreme fidelity at very low cost and also the role of recombinations of software for novelty production. Gershenfeld (2014, 2017) has put forward a model for 21st century digital fabrication which relies on programmed 3-D self-assembly of digitized materials which he claims biology solved over 3.5 billion years ago with the ribosomal self-assembly model. Markose (2021a) used this insight to show how the relevance to biology for the staple of G-T-P, viz. the ***Diag (.)*** operator where a program *m* implements the machine that runs *m*. However, as pointed out as only software operations can change the information content of software, regardless of the large scope for benign changes to software, the Achilles heel of digital systems is that they can be hacked by malign software.
 The other major development of the 21 st century digital age is the astounding invention of the blockchain distributed ledger technology, first presented in the anarchic agenda of the Bitcoin by pseudonymous Satoshi Nakamoto (2009) to resist centralized state control of monetary systems. BCDLT permits decentralized software based record keeping of actions of multiple agents in which the fidelity of extant digital accounts is maintained by a software solution to a cryptographic puzzle which makes it difficult for malign activity in new software additions by a subset of agents. While there are yet major challenges associated with the man-made BCDLT systems, what the unique **G-T-P** block chain DLT of the eukaryote genomic system shows is that when the powers of recursive recombinations and proteanism are unleashed within digital systems, if this is not embedded in a BCDLT, it will be doomed to failure and hacked to pieces. Again the unique nature of block chain DLT in genomic systems was first pointed out by Abramov et. al. (2021 a) and Markose (2021a) with the latter giving key details on this phenomenally successful ancient precedent. The highly conserved building blocks of life being virtually unchanged for 3.5 billion years while novelty is added on is a testament of genomic intelligence which AI is unlikely to achieve as its design principles are still too reliant on target driven formulations and statistical models for novelty.

**References**

Abramov, O., Bebell, K.L. & Mojzsis, S.J. Emergent Bioanalogous Properties of Blockchain-based Distributed Systems. *Orig Life Evol Biosph* **51,**131–165 (2021). <https://doi.org/10.1007/s11084-021-09608-1>

Acocella, N. Di Bartolomeo, G. and A. Hughes Hallett (2021), The Theory of Economic Policy in a Strategic Context, Cambridge University Press.

Albin, P. 1998. *Barriers and Bounds to Rationality, Essays on Economic Complexity and Dynamics in Interactive Systems*, Edited and with an Introduction by Duncan Foley, Princeton University Press.

Amaral, P.P, Dinger, M.E, Mercer, T.R and Mattick, J.S. 2008.“The Eukaryote Genome as an RNA Machine”, *Science* 319: 1787-1789.

Arbib, M.and Fagg, A.1998. “Modeling parietal-premotor interactions in primate control of grasping”*Neural Networks*, 11, pp. 1277–1303.

Barto, A. , Mirolli, M. and G. Baldasarre, 2013, Novelty or Surprise ? Front. Psychol., 11 December 2013 | <https://doi.org/10.3389/fpsyg.2013.00907>

Baumol, W. 2002. The Free Market Innovation Machine, Princeton University Press.

Baumol, W. 2004.“Red Queen games: arms races, rule of law and market economies”,*Journal of Evolutionary Economics*, vol. 14(2), pp. 237–47.

Beinhocker, E. 2011. “Evolution as Computation: Integrating Self-Organization with Generalized Darwinism,” *Journal of Institutional Economics*, 7, 3, 393-423.

Binmore, K. 1987.“ Modelling Rational Players: Part 1”, *Journal of Economics and Philosophy*, 3, 179-214.

Bhatt, M. and C. Camerer .2005. “Self-referential thinking and equilibrium as states of mind in games: FMRI evidence”. *Games and Economic Behaviour 52:424–459.*

##### Blobel, G. ( 1999) The Nobel Prize in Physiology or Medicine 1999

https://www.nobelprize.org/prizes/medicine/1999/summary/

Bostrom, N (2014), Superintelligence: Paths, Dangers, Strategies, OUP.

Byrne, R.,Whiten,A.1988.Machiavellian Intelligence: Social Expertise and the Evolution of Intellect in Monkeys, Apes, and Humans, Oxford University ,Press, Oxford.

[Brynjolfsson, E.](https://library.villanova.edu/Find/Author/Home?author=Brynjolfsson%2C+Erik%2C), [McAfee, A. (2014)](https://library.villanova.edu/Find/Author/Home?author=McAfee%2C+Andrew%2C), The Second Machine Age: Work, Progress and Prosperity In a Time of Brilliant Technologies, New York : W. W. Norton & Company, [2014]

 Buckmann, M. , A. Haldane, A. Hüser, (2021) Comparing minds and machines: implications for financial stability, Oxford Review of Economic Policy, Volume 37, Issue 3, Autumn 2021, Pages 479–508, <https://doi.org/10.1093/oxrep/grab017>

Camerer, C., Loewenstein, G., Prelec, D. 2005. “Neuroeconomics: How neuroscience can inform economics”, Journal of Economic Literature , 43 (1), 9–64.

Casti, J., (1994). *Complexification : Explaining A Paradoxical World Through the Science of Surprises* , London Harper Collins.

Chaitin G. 2013. Life as Evolving Software, in: A Computable Universe: Understanding and Exploring Nature as Computation. Edited by H. Zenil,World Scientific, Singapore 2013, pp. 277–302.

Chaitin G. 2012. Proving Darwin: Making Biology Mathematical, Pantheon Books, New York.

Colander, D. (ed.) .2000. The Complexity Vision and the Teaching of Economics, E. Elgar, Cheltenham, UK.

Colander, D., M. Goldberg, A. Haas, K. Juselius, T. Lux, H. Föllmer, A. Kirman, B. Sloth.2009. “The Financial Crisis and the Systemic Failure of the Economics Profession,” *Critical Review*, 21, 2.

Colombo, M., Palacios, P. Non-equilibrium thermodynamics and the free energy principle in biology. *Biol Philos* **36,**41 (2021). https://doi.org/10.1007/s10539-021-09818-x

Cutland, N.J. 1980.*Computability: An Introduction to RecursiveFunction Theory*, Cambridge University Press.

Day, R. (1984), Disequilibrium Economic Dynamics: A Post-Schumpeterian Contribution, Journal of Economic Behavior and Organization, Vol. 5, Issue 1, March, pp. 57-76.

Day, R. (2007), The mechanisms of economic evolution: completing Schumpeter’s theory, Chapter 46, pp. 745-753, in: Elgar Companion to Neo-Schumpeterian Economics edited by Horst Hanusch & Andreas Pyka, Edward Elgar, Cheltenham, UK.

[Dawkins, R.](https://en.wikipedia.org/wiki/Richard_Dawkins)1989. The Extended Phenotype.[*Oxford*](https://en.wikipedia.org/wiki/Oxford): [*Oxford University Press*](https://en.wikipedia.org/wiki/Oxford_University_Press).

Danan-Gotthold, M., [Guyon](https://www.ncbi.nlm.nih.gov/pubmed/?term=Guyon%20C%5BAuthor%5D&cauthor=true&cauthor_uid=27776542), C. , [Giraud](https://www.ncbi.nlm.nih.gov/pubmed/?term=Giraud%20M%5BAuthor%5D&cauthor=true&cauthor_uid=27776542), ., [Levanon](https://www.ncbi.nlm.nih.gov/pubmed/?term=Levanon%20EY%5BAuthor%5D&cauthor=true&cauthor_uid=27776542), E. , [Abramson](https://www.ncbi.nlm.nih.gov/pubmed/?term=Abramson%20J%5BAuthor%5D&cauthor=true&cauthor_uid=27776542), J. 2016. “Extensive RNA editing and splicing increase immune self-representation diversity in medullary thymic epithelial cells”, [*Genome Biol*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5078920/)*ogy*. (2016) ; 17: 219.

Derbinski, J.et al.  .2001. “Promiscuous gene expression in medullary thymic epithelial cells mirrors the peripheral self ”, *Nature. Immunology*, 2, 1032 -1039.

Dhami, S. 2016. *The Foundations of Behavioral Economic Analysis,* Oxford University Press.

[Dobzhansky, T.](https://en.wikipedia.org/wiki/Theodosius_Dobzhansky)1973."Nothing in Biology Makes Sense Except in the Light of Evolution", [*American Biology Teacher*](https://en.wikipedia.org/wiki/American_Biology_Teacher), **35** (3): 125–129.

Durlauf, S. 2012. “Complexity, Economics and Public Policy”, *Politics, Philosophy and Economics*, 11(1), 45-75.

Eichengreen, B. 2010. “Globalization and the Crisis”, In Article provided by Ifo Institute for Economic Research at the University of Munich in its journal [CESifo Forum](http://ideas.repec.org/s/ces/ifofor.html). Volume 11 (2010) Issue (Month): 3 (October), pp. 20-24.

Fatouh, M., Markose, S. and Giansante, S. 2019. “[The impact of quantitative easing on UK bank lending: Why banks do not lend to businesses?](http://repository.essex.ac.uk/24409/)” Journal of Economic Behavior and Organization, <https://doi.org/10.1016/j.jebo.2019.02.023>

Fadiga, L., Fogassi, L., Pavesi, G., and Rizzolatti, G. 1995. Motor Facilitation During Action Observation: A Magnetic Stimulation study. *Journal of Neurophysiology* 73, 2608-2611.

Fedoroff, N.V. Transposable elements, epigenetics and genome evolution. *Science* **2012**, *338*, 758–767. [[**Google Scholar**](https://scholar.google.com/scholar_lookup?title=Transposable+elements,+epigenetics+and+genome+evolution&author=Fedoroff,+N.V.&publication_year=2012&journal=Science&volume=338&pages=758%E2%80%93767&doi=10.1126/science.338.6108.758)] [**[CrossRef](https://doi.org/10.1126/science.338.6108.758%22%20%5Ct%20%22_blank)**]

Fitch, T. 2014.“Toward a computational framework for cognitive biology:Unifying approaches from cognitive neuroscience and comparative Cognition”, *Physics of Life Reviews*,11 329–364.

Flajnik, M.F.; Kasahara, M. Origin and evolution of the adaptive immune system: Genetic events and selective pressures. *Nat. Rev. Genet.* **2009**, *11*, 47–59. [[**Google Scholar**](https://scholar.google.com/scholar_lookup?title=Origin+and+evolution+of+the+adaptive+immune+system:+Genetic+events+and+selective+pressures&author=Flajnik,+M.F.&author=Kasahara,+M.&publication_year=2009&journal=Nat.+Rev.+Genet.&volume=11&pages=47%E2%80%9359&doi=10.1038/nrg2703&pmid=19997068)] [**[CrossRef](https://doi.org/10.1038/nrg2703%22%20%5Ct%20%22_blank)**] [[**PubMed**](https://www.ncbi.nlm.nih.gov/pubmed/19997068)]

Friston K . 2010. The free-energy principle: a unified brain theory? Nat Rev Neurosci. 11:127–138.

Friston K. 2013 Life as we know it. J R Soc Interface 10: 20130475. http://dx.doi.org/10.1098/rsif.2013.0475

Gallese, V and Sinigaglia, C. 2011. "What is so special about embodied simulation?" *Trends in Cognitive Sciences*, Vol. 15 No. 11, p 515.

Gallese, V. 2009. “Mirror neurons, embodied simulation, and the neural basis of social identification”, *Psychoanalytic Dialogues*, Vol. 19 No. 5, pp. 519–536.

Gallese, V., Fadiga, L.,Fogassi, L.,Rizzolatti, G.1996.["Action recognition in the premotor cortex"](http://brain.oxfordjournals.org/cgi/content/abstract/119/2/593).*Brain***119** (2): 593–609.

Gershenfeld, N. 2012. “How To Make Anything : The Digital Fabrication Revolution”, In, Fourth Industrial Revolution, The Davos Reader, Edited by Gideon Rose.

Gershenfeld, N. Gershenfeld, A. and J Cutcher-Gershenfeld (2017) Designing Reality: How to Survive and Thrive in the Third Digital Revolution, Basic Books, Hachette Book Group, New York.

Gödel, K. 1931. ‘On Formally Undecidable Propositions of *Principia Mathematica* and Related Systems’(Translation in English in *Gödel’s Theorem in Focus,* ed. .S.G Shanker, 1988, Croom Helm).

Goodhart, C. 1994. “Game Theory for Central Bankers: A Report to the Governor of the Bank of England”, *Journal of Economic Literature*, vol. 32, pp. 101-15.
Goodhart, C. 1981. “Problems of Monetary Management: The U.K Experience”, In Courakis, A. S. (ed) *Inflation, Depression and Economic Policy in the West*, pp. 111-146.

Greenen, V. The thymus and the science of self. *Semin. Immunopathol.* **2021**, 1–10. [[**Google Scholar**](https://scholar.google.com/scholar_lookup?title=The+thymus+and+the+science+of+self&author=Greenen,+V.&publication_year=2021&journal=Semin.+Immunopathol.&pages=1%E2%80%9310&doi=10.1007/s00281-020-00831-y)] [**[CrossRef](https://doi.org/10.1007/s00281-020-00831-y%22%20%5Ct%20%22_blank)**]

Hughes Hallett, Andrew J. (1989). "Econometrics and the Theory of Economic Policy: The Tinbergen–Theil Contributions 40 Years On". Oxford Economic Papers. **41** (1): 189–214. [*doi*](https://en.wikipedia.org/wiki/Doi_%28identifier%29):[*10.1093/oxfordjournals.oep.a041892*](https://doi.org/10.1093/oxfordjournals.oep.a041892). [*JSTOR*](https://en.wikipedia.org/wiki/JSTOR_%28identifier%29) [*2663189*](https://www.jstor.org/stable/2663189).

Hanusch, H. & A. Pyka. (2007) Elgar Companion to Neo-Schumpeterian Economics edited by, Edward Elgar, Cheltenham, UK.

Hayek, F.A. 1967: “The Theory of Complex Phenomena”, in *Studies In Philosophy, Politics, and Economics*, The University of Chicago Press, Chicago.

Hayek, F.A. 1952. The Sensory Order: An Inquiry Into the Foundations of Theoretical Psychology, Chicago, IL Chicago University Press.
Haldane, A. 2012. “Financial Arms Races”, Speech delivered at the Institute for New Economic Thinking, Berlin, 14 April 2012.

# Heaven, D. 2019 “Why deep-learning AIs are so easy to fool: Artificial-intelligence researchers are trying to fix the flaws of neural networks”. Nature, News Feature https://www.nature.com/articles/d41586-019-03013-5

Holland, J.1975.*Adaptation in Natural and Artificial Systems*, MIT Press.

Hirschman, A.(1991).*The Rhetoric of Reaction: Perversity, Futility, Jeopardy,*Theelknap Press of Harvard University Press, England.

Hofstader, D. 1999.Godel, Escher, Bach: An Eternal Golden Braid, Basic Books.

Janeway, C.A., Travers, P.,Walport, M.; Shlomchik, M.J. .2005. *Immunobiology* (6th ed.). Garland Science.

Jones, D.2000. “Emerging Problems with the Basel Capital Accord: Regulatory Capital Arbitrage and Related Issues”, No 24, pages 35-58.
Kapitonov, V.V.; Jurka, J. RAG1 core and V(D)J recombination signal sequences were derived from Transib transposons. *PLoS Biology.* **2005**, *3*, e181. [[**Google Scholar**](https://scholar.google.com/scholar_lookup?title=RAG1+core+and+V(D)J+recombination+signal+sequences+were+derived+from+Transib+transposons&author=Kapitonov,+V.V.&author=Jurka,+J.&publication_year=2005&journal=PLoS+Biol.&volume=3&pages=e181)]

Kaesar, G., J. Chun (2020) **“**Brain cell somatic gene recombination and its phylogenetic foundations”
Journal of Biological Chemistry,[Volume 295, Issue 36](https://www.sciencedirect.com/journal/journal-of-biological-chemistry/vol/295/issue/36), 4 September 2020, Pages 12786-12795

Kleene, Stephen Cole (1952). *Introduction to Metamathematics*. North-Holland.

Kyewski, B and Klein, L. 2006. “A Central Role For Central Tolerance” *Annual Review of Immunology*, Vol. 24:571-606.

Langton, Chris (1990) Computation at the Edge of Chaos: Phase Transitions and Emergent Computation, Physica D 42 (1990) 12-37 North-Holland

## Lopes, P. 2017. “Why are behavioural and immune traits linked ?” [Hormones and Behavior](https://www.sciencedirect.com/science/journal/0018506X)

[Volume 88](https://www.sciencedirect.com/science/journal/0018506X/88/supp/C), pp. 52-59.

Lucas, R. 1972. “ Expectations and the Neutrality of Money”, *Journal of Economic Theory*, 4, pp.103-24.

Lucas, R.1976. “Econometric Policy Evaluation: A Critique”, Carnegie-Rochester Conference Series on Public Policy, vol. 1, pp.19-46.

### Markose, S.M. (2021a) Genomic Intelligence as Über Bio-Cybersecurity: The Gödel Sentence in Immuno-Cognitive Systems. *Entropy* 2021, *23*, 405. <https://doi.org/10.3390/e23040405>

Markose, S.M. (2021b) Novelty production and evolvability in digital genomic agents: Logical foundations and policy design implications of complex adaptive systems. In *Complex Systems in the Social and Behavioral Sciences: Theory, Method and Application*; Elliot, E., Douglas Kiel, L., Eds.; Michigan University Press: Ann Arbor, MI, USA, 2020. [[**Google Scholar**](https://scholar.google.com/scholar_lookup?title=Novelty+production+and+evolvability+in+digital+genomic+agents:+Logical+foundations+and+policy+design+implications+of+complex+adaptive+systems&author=Markose,+S.M.&publication_year=2020)]

Markose, S. M (2021,c) How we became smart- a journey of discovery through the world of game theory and genomic intelligence, Essex Blog, 26 October 2021,<https://www.essex.ac.uk/blog/posts/2021/10/26/how-we-became-smart>

Markose, S.M..2019. “The Digital Origins of Intelligence: How we became Smart and Protean”, Keynote Talk at 2019 Bio-Inspired ICT (BICT) Conference, Carnegie Mellon University, <http://bionetics2019.eai-conferences.org/keynotes/>

Markose, S.M. 2017.“Complex type 4 structure changing dynamics of digital agents: Nash equilibria of a game with arms race in innovations *Journal of Dynamics and Games*,4(3),255-284.

Markose, S. 2013. “[Systemic risk analytics: A data-driven multi-agent financial network (MAFN) approach](http://lnx.acefinmod.com/wp-content/uploads/2018/11/jbr201310Markosepreprint.pdf)”. *Journal of Banking Regulation,* 14(3-4), pp.285-305.

Markose, S.M.2005. “Computability and Evolutionary Complexity: Markets as Complex Adaptive Systems (CAS)”, *Economic Journal ,*vol.115, pp.F159-F192.

Markose, S.M, 2004, “Novelty in Complex Adaptive Systems (CAS): A Computational Theory of Actor Innovation”, *Physica A: Statistical Mechanics and Its Applications*,vol. 344,pp. 41- 49.

McClintock,B.1984.“The significance of responses of the genome to Challenge”, *Science* 226 (4676), 792-801.

Müller, V.; De Boer, R.J.; Bonhoeffer, S.; Szathmáry, E. An evolutionary perspective on the systems of adaptive immunity. *Biol. Rev.* **2018**, *93*, 505–528. [[**Google Scholar**](https://scholar.google.com/scholar_lookup?title=An+evolutionary+perspective+on+the+systems+of+adaptive+immunity&author=M%C3%BCller,+V.&author=De+Boer,+R.J.&author=Bonhoeffer,+S.&author=Szathm%C3%A1ry,+E.&publication_year=2018&journal=Biol.+Rev.&volume=93&pages=505%E2%80%93528&doi=10.1111/brv.12355&pmid=28745003)] [**[CrossRef](https://doi.org/10.1111/brv.12355%22%20%5Ct%20%22_blank)**] [[**PubMed**](https://www.ncbi.nlm.nih.gov/pubmed/28745003)]

Nachbar J.H and Zame, W.R. 1996., “Non-computable Strategies and Discounted Repeated Games”, *Economic Theory,* vol*.*, pp.111–121.

Nakamoto, S., 2008. Bitcoin: A Peer to Peer Electronic Cash System. <https://bitcoin.org/bitcoin.pdf>

Noia.J.M. and Neuberger, M.S. 2007. “Molecular mechanisms of antibody somatic hypermutation”, *Annual Review of Biochemistry*,76:1-22.

Post, E.1944. “Recursively Enumerable Sets of Positive Integers and Their Decision Problems”, *Bulletin of American Mathematical Society,* vol.50, pp.284-316.

# [Prokopenko M.,](https://www.sciencedirect.com/science/article/pii/S1571064519300077?via%3Dihub" \l "!) [Harré](https://www.sciencedirect.com/science/article/pii/S1571064519300077?via%3Dihub" \l "!), M. ,[Lizier](https://www.sciencedirect.com/science/article/pii/S1571064519300077?via%3Dihub#!) J., [Boschetti](https://www.sciencedirect.com/science/article/pii/S1571064519300077?via%3Dihub#!) F.[,Peppas, P.](https://www.sciencedirect.com/science/article/pii/S1571064519300077?via%3Dihub#!) [Kauffma](https://www.sciencedirect.com/science/article/pii/S1571064519300077?via%3Dihub" \l "!)n, S. 2019. “Self-referential basis of undecidable dynamics: From the Liar paradox and the halting problem to the edge of chaos”, [*Physics of Life Reviews*](https://www.sciencedirect.com/science/journal/15710645), <https://www.ncbi.nlm.nih.gov/pubmed/30655222> .

Ramachandran,V.S .2000. “Mirror Neurons and imitation learning as the driving force behind the great leap forward in human evolution”, EDGE, Conversation, May 5 2000.

Rescorla, M. 2020, "The Computational Theory of Mind", The Stanford Encyclopedia of Philosophy (Fall 2020 Edition), Edward N. Zalta (ed.), <https://plato.stanford.edu/archives/fall2020/entries/computational-mind/>.

Rizzolatti, G., L. Fadiga, V. Gallese, L. Fogassi .1996. “Premotor cortex and the recognition of motor actions”,*Cognitive Brain Research*, 3 (1996), pp. 131–141.
Rogers, H.1967. *Theory of Recursive Functions and Effective Computability,*McGraw-Hill.

Rogoff, K. 1985. “The optimal degree of commitment to an intermediate monetary target”, *Quarterly Journal of Economics,* Nov. , pp.169-90.

Romer, P. 2016. “The Trouble With Macroeconomics”, The American Economist.

Schwartenbeck, P., T. FitzGerald, R. Dolan, K. Friston (2013) Exploration, novelty, surprise, and free energy minimization, Front. Psychol., 07 October <https://doi.org/10.3389/fpsyg.2013.00710>

Schumpeter, J. A. 1934. The theory of economic development : an inquiry into profits, capital, credit, interest and the business cycle. Cambridge, Massachusetts, Harvard University Press.

Schumpeter, J.A, 1942. Capitalism, Socialism and Democracy, Harper & Bros, New York.

Schelling, T. 1971. “Dynamic Models of Segregation”, *Journal of Mathematical Sociology*, 161.pp. 143-186.

Sánchez-Ramón, S.; Faure, F. Self and the Brain: The Immune Metaphor. *Front Psychiatry.* **2020**, *11*, 540676. [[**Google Scholar**](https://scholar.google.com/scholar_lookup?title=Self+and+the+Brain.+The+Immune+Metaphor&author=S%C3%A1nchez-Ram%C3%B3n,+S.&author=Faure,+F.&publication_year=2020&journal=Front+Psychiatry.&volume=11&pages=540676&doi=10.3389/fpsyt.2020.540676)] [**[CrossRef](https://doi.org/10.3389/fpsyt.2020.540676%22%20%5Ct%20%22_blank)**]

Smullyan, R. 1961.*Theory of Formal Systems*, Princeton University Press.
Soros, G.1995. *Soros on Soros: Staying Ahead of the Curve,* John Wiley.

# Tognoli E., Lagarde, J., DeGuzman G., Kelso, S. (2007) “The phi Complex as the Neuromarkerof Human Social Coordination”, *Proceedings of the National Academy of Sciences of the USA, Vol 104/No.19, pp 8190-8195.*

Tsuda, I. .2014.Logic Dynamics for Deductive InferenceIts Stability and Neural Basis, Chapter 17 In, Chaos, Information Processing and Paradoxical Games: The Legacy of John S Nicolis. Edited by Nicolis Gregoire and Basios Vasileios, World Scientific Publishing Co. Pte.Ltd., 2014.

Turing, A. M. 1936. On computable numbers, with an application to the Entscheidungsproblem.

*Proceedings of the London Mathematical Society.* **42**, 230–265. (doi:10.1112/plms/s2-42.1.230)

Siedliński, R., (2016) “ Turing Machines and Evolution: A Critique of Gregory Chaitin’s Metabiolog Studies, *Logic, Grammar and Rhetoric*, 48 (61).

Skylar Tibbits (2012) Digital Materials to Self-Assembly , <https://www.acsarch.org/proceedings/Annual%20Meeting%20Proceedings/ACSA.AM.100/ACSA.AM.100.30.pdf>

Walker, S.I.; Davies, P.C.W. The algorithmic origins of life. *J. R. Soc. Interface* **2013**, *10*, 20120869. [[**Google Scholar**](https://scholar.google.com/scholar_lookup?title=The+algorithmic+origins+of+life&author=Walker,+S.I.&author=Davies,+P.C.W.&publication_year=2013&journal=J.+R.+Soc.+Interface&volume=10&pages=20120869&doi=10.1098/rsif.2012.0869&pmid=23235265)] [**[CrossRef](https://doi.org/10.1098/rsif.2012.0869%22%20%5Ct%20%22_blank)**] [[**PubMed**](https://www.ncbi.nlm.nih.gov/pubmed/23235265)]

Witt, U. 2007. Why Novelty Is Essential for Economic Evolution – and Why It Is so Hard to Analyze Paper presented at the EAEPE Conference 2007 in Porto.

Wolfram, 2002, S. [*A New Kind of Science.*](http://www.amazon.com/exec/obidos/ASIN/1579550088/ref%3Dnosim/ericstreasuretro) Champaign, IL: Wolfram Media, pp. [32](http://www.wolframscience.com/nksonline/page-32-text)-38, [52](http://www.wolframscience.com/nksonline/page-52-text), [675](http://www.wolframscience.com/nksonline/page-675-text)-691, [851](http://www.wolframscience.com/nksonline/page-851-text), and [1115](http://www.wolframscience.com/nksonline/page-1115c-text)-1116.

Zador, A. M. (August 2019) A critique of pure learning and what artificial neural networks can learn from animal brains. Nat Commun, 10 (1). p. 3770. ISSN 2041-1723.

1. For the writing of this draft of the paper, I’m grateful for discussions with Charles Goodhart, Ken Binmore, Patrick Grim, Michael Rescorla, Karl Friston, Rosemary Nagel, Matteo Colombo, Charles Gallistel and Oron Shagrir. [↑](#footnote-ref-1)
2. Bhatt and Camerer (2005) succinctly state this: "in a Nash equilibrium nobody is surprised about what others actually do, or what others believe, because strategies and beliefs are synchronized, presumably due to introspection, communication or learning." [↑](#footnote-ref-2)
3. The following characteristics have typically been listed as being pertinent for complexity: non-linear dynamics, power laws and fat tailed extreme events, socio-economic interconnectedness and network models, fractality, self-organization and emergence. A large class of spectacular phenomena can only emerge or self-organize such as pattern formation in shoals of fish or flock of birds and even racial segregation, as in the Schelling (1971) model. There is, no doubt, that it is important to understand tipping points and sudden phase transitions in non-linear models. However, novelty production by highly intelligent agents is rarely mentioned as a causal factor in complex systems in Complexity Economics. [↑](#footnote-ref-3)
4. The Red Queen, the character in Lewis Carol’s *Alice Through the Looking Glass*, who signifies the need ‘to run faster and faster to stay in the same square’ has become emblematic of the outcome of competitive co-evolution for evolutionary biologists in that no competitor gains absolute ground. Baumol (2002) shows how Red Queen type arms race in product or process innovation is undertaken by firms simply to maintain status quo in market share in the face of competitors. [↑](#footnote-ref-4)
5. The reader is directed to Markose (2021,c) Essex Blog for an informal discussion of the Binmore (1987) critique of game theory and how it paves the way for a model for genomic intelligence as a unique digital self-referential information processing framework capable of endogenous open-ended novelty production in a structure of an arms race See, <https://www.essex.ac.uk/blog/posts/2021/10/26/how-we-became-smart> [↑](#footnote-ref-5)
6. Dynamics of Type’s I-III in the Wolfram-Chomsky Schema do not produce novelty, and in sequence, they achieve limit points, limit cycles and chaotic dynamics. As most modelling of dynamical systems is based on equations, modellers to date can at best produce chaotic dynamics and many mistakenly think this the pinnacle of complex dynamics. Some have pointed out that Type IV dynamics in digital systems can be found in the Wolfram Cellular Automata Rule 110 (see Wolfram, 2002) and cite this as proof of concept how simple rules can sometimes produce complex irregular structure changes and novel patterns that do not repeat periodically. [↑](#footnote-ref-6)
7. Prokopenko et.al. (2019) is unique in trying to identify the exact Gödel conditions of Self-Reference and ‘inverter machine’ as in Gödel’s Liar in the class of Wolfram Cellular Automata Rule 110 as a prelude for novelty production. [↑](#footnote-ref-7)
8. General recursive functions or computable functions are number theoretic functions involving finite steps of instructions, called an algorithm or a program, operating on integers representing encoded information given in finite strings of symbols and map to similar integers as outputs should the procedure halt. General recursive functions include all elementary arithmetic,logiccal operations and also functions obtained from substitution, iteration and recursion, In the latter, functions call on themselves and use as inputs what are outputs from previous calculations. In this paper, I use notation from Cutland (1980) and Rogers (1967). [↑](#footnote-ref-8)
9. The notion of a surprise strategy appears in the so called Lucas surprise supply function often defined as follows:
y= y\* + b( - e ) +  . This says that output, y, will not increase beyond the natural rate, y\*, unless there is ‘surprise’ inflation, ( - e) which is the prediction error from expected inflation, e. The idea here is that the private sector contravenes the effects of anticipated inflation, viz. the neutrality result. Hence, it is intuitively asserted that authorities who seek to expand output beyond the natural rate need to use ‘surprise’ inflation. [↑](#footnote-ref-9)
10. See Haldane (2012) on financial arms races and the £14 Trillion dollar shadow banking that grew from arbitrage activities of regulatees responding to the Basel Banking regulation on capital requirements. Eichengreen (2010) concludes :“fundamentally, the (2008) crisis is the result of flawed regulations and perverse incentives in financial markets, ” [↑](#footnote-ref-10)
11. Charles Goodhart is reputedly to have said regarding the ill fated defence of the currency pegs : “If at the first whiff of trouble it is advisable to float, Why Peg ?” [↑](#footnote-ref-11)
12. Acocella et. al (2012) acknowledge that the interest rate policy with the inflation targeting “ is in many ways in the tradition of the classic Jan Tinbergen (1952)/Henri Theil (1961) (TT) targets and instruments problem. As with TT, the combination of quadratic loss and linear constraints yields a certainty equivalent decision rule for the path of the instrument.” [↑](#footnote-ref-12)
13. Lucas (1076) states : “any change in policy will systematically alter the structure of economic models . . . for the question of short- term forecasting, or tracking ability of econometric models . . . this conclusion is of only occasional significance . . . [but] for issues involving policy evaluation, in contrast, it is fundamental”. [↑](#footnote-ref-13)
14. Rescorla (2020) summarizes this unfortunate state of affairs saying “There is wide consensus that the criticism if Computational Theory of Mind lacks any force. It may turn out that certain human mental capacities outstrip Turing-computability, but Godel’s incompleteness theorems provide no reason to anticipate this outcome.” [↑](#footnote-ref-14)
15. Papers (see [[**78**](https://www.mdpi.com/1099-4300/23/4/405/htm#B78-entropy-23-00405),[**79**](https://www.mdpi.com/1099-4300/23/4/405/htm#B79-entropy-23-00405)]) that use the Gödel (1931) formalism, which predates recursive function theory, generates the Gödel (1931) sentence that typically takes the form: PA ͰA ↔ ¬Prov(A). Here, A effectively says of itself that it is not provable (¬Prov(A)), with this undecidable proposition being a theorem (Ͱ) in the formal system of Peano Arithmetic (PA). [↑](#footnote-ref-15)
16. The neurons that fire with actual action execution by are called *canonical neurons* (Arbib and Fagg (1998)) and correspond to on-line machine executions by self in the **G-T-P** logic. [↑](#footnote-ref-16)
17. Many computational cognitive models rely on Bayesian learning. As stated in Fitch (2014) the recordings from the sensory-visual and motor cortex constitute “a large, complex and ancient set of Bayesian priors (visual, sensory, motor) that constrain inference in any mammalian brain, and are equally operative in the human brain”. Bayesian inference is statistical and is a far cry from inference by embodied offline simulation in the **G-T-P** cognitive system, which also permits novelty generation. [↑](#footnote-ref-17)
18. Prokopenko et. al (2019) associate the Wolfram Rule 110 for cellular automata (CA) irregular structure changes and novel patterns with Gödel undecidability and incompleteness results. The authors state: “while the key role played by self-reference in proofs of undecidability in various computational frameworks is beyond doubt, its precise use in dynamical systems, and CAs specifically, has not been demonstrated explicitly”. They aim to reconstruct the key element of a self-referential format of the negation/inverter machine in a Gödel type proof for CAs that are capable of novelty producing Type IV dynamics. [↑](#footnote-ref-18)
19. Given a set of N elements, its power set has 2N members. Hence, the 2N sets cannot be put in 1-1 correspondence with N. The notion of epistemic incompleteness of the brain, was first introduced to me in Hayek’s book on cognitive neuro-science that of necessity the brain is incomplete. There were more procedures than those that can be formalizable and enumerable [↑](#footnote-ref-19)
20. The first limitative result on functions computable by T.Ms is that at most there can only be a countable number of these with the cardinality of being denoted by *0*, while from Cantor we know that the set of all number theoretic functions have cardinality of *20*. Hence, not all number theoretic functions are computable (see,Cutland,1980 ). [↑](#footnote-ref-20)
21. Note, analog measurements of state variables, such as chemical concentration, temperature etc, have to converted into digital code in order for this to be processed by a digital agent. [↑](#footnote-ref-21)
22. It is well known by what is called the SMN Theorem or the Parameterization Theorem (Rogers, 1967) how new g.ns for recursive operations on extant g.ns can be mechanically generated. [↑](#footnote-ref-22)
23. On updating (12.a) and (12.b) the Liar/Malware strategy gn¬ now operates on itself, we have =  , which is a contradiction. [↑](#footnote-ref-23)
24. It is beyond the scope of this chapter to give the detailed recursive bio-informatics behind the somatic hyper mutations (Noia and Neuberger 2007) on B-cells that follow from this point in the host adaptive immune system. The same is the case on how retrotransposon activity can change the germline. [↑](#footnote-ref-24)
25. For instance, consider the Nachbar and Zame (1996) conclusion that “for a large class of discounted repeated games (including the repeated Prisoner's Dilemma) there exist strategies implementable by a Turing machine for which *no* best response is implementable by a Turing machine”. The Post (1944) set theoretic proof of the Gödel incompleteness result shows that that from fully deducible non-computable fixed points of a game as in the Gödel sentence in (8), the *only* (italics added) best response strategies that can be implemented by total recursive functions, viz. Turing machines, are those that satisfy the property of productive functions that syntactically produce objects that lie outside given recursively enumerable sets. [↑](#footnote-ref-25)
26. Chaitin’s critics have noted that in terms of implementation, the so called ‘creative’ aspects of the accretion of new and different software ends up being teleological in that only improvements to a n-bit Busy Beaver Function are sought (see, Siedlinksi 2016 ). [↑](#footnote-ref-26)
27. Goodhart’s Law claims that *“any observed statistical regularity will tend to collapse once pressure is placed upon it for control purposes”* (Goodhart, 1981) [↑](#footnote-ref-27)
28. Since the development of evolutionary computation such as Genetic Algorithms (Holland (2012)) or Reinforcement Learning and other frameworks such as the Friston Free Energy (Friston, 2013), the search space for actions is not prespecified and the stated objective, respectively maximizing fitness/reward or minimizing entropy, provides a guide for search which are often confronted by a tradeoff between exploration and committing to an action. These frameworks, as is the case with been found with Deep Learning AI are particularly vulnerable to adversarial agents (see, Heaven, (2019)). [↑](#footnote-ref-28)