**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 blockchain distributed ledger. This initially developed in the AIS, which from the get-go accounts 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, models of bounded rationality and 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”.

Of the Austrian economists, Schumpeter (1934, 1941) has had an enduring influence in placing innovative disruptive forces at the centre of economic phenomena. [[5]](#footnote-5) 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. Many have acknowledged that Hayek is a pioneer of the idea that socio-economic and cognitive systems are complex phenomena (Gaus, 2006) and some parallels have been drawn between this and the more recent developments by the Santa Fe Institute Complexity Economics (Moreno-Casas and Bagus, 2022, Fontana,2010). However, these and other studies (Bowles et.al., 2017) have chosen to ignore that Hayek’s espousal of open-endedness of knowledge acquisition in society and opposition to centralized control to achieve specific objectives for society as whole, which Hayek calls constructivist reason (Hayek, 1967, Chapter 5), relies on Gödel Incompleteness theorems. Admittedly, Hayek’s position on this in, Hayek (1952), takes a very rudimentary form as in Cantor’s proof on the uncountable regarding there being more putative objects than can be listed by any enumeration algorithm (see, Markose, 2005, 2002, Section 1.2 ), van den Hauwe (2011, Section 3.2.2), Holm, 2014, Rosser, 2012). Hayek’s libertarian defence for autonomy of individual action is on the grounds that such potentially non-denumerable infinite capacity for ‘tacit’ knowledge, a veritable fount of novelty, will be lost as it can only be precipitated in uncoerced human actions. Hayek’s large body of work, Hayek (1973, 1976, 1979) on political economy was on the regulatory structures that secure freedom from coercion for individuals to pursue by their autonomy of actions an open-ended distributed knowledge base that no central authority can possess (Hayek, 1945). Hayek proposes Kantian style non-purposive or end-neutral rules for implementation by the state that are not specific but universalizable rules over all humans with their implementation guided primarily by abstract principles of consistency rather than utility (Markose,1987, 2021b). Interestingly, as noted by Holm (2014), Hayek presaged not only that centralized control by rules that impose prespecified objectives for society as a whole will reduce complexity of the system and its corollary is that novelty is curtailed (Lehman and Stanley, 2011). Hayek gave dire prognosis of system failure and collapse of the liberal order in works like *The Fatal Conceit*, Hayek (1968), if there is flagrant disregard for individual autonomy in the achievement of societal objectives. The nexus between autonomy of the individual and open-ended search for novelty as part of complex adaptive systems remains poorly investigated.

Indeed, the above noted oversight has led many contemporary Austrian economists and complexity economists to see no distinction between Hayek’s Gödel Incompleteness based epistemic for open-ended and distributed complexity and the Herbert Simon (1955) bounded rationality critique of the utility maximizing framework of Neoclassical economics.[[6]](#footnote-6) Simon’s critique on the absence of the procedural lacunae of how the optimal outcome is implemented in practice, beyond the substantive statement of first order optimality conditions for a suitably shaped utility/objective function (see, Dixon, 2012), is a compelling one. Simon focuses on a threshold dependent framework of satisficing, which may involve a judicious pruning of complexity and lead to the adoption of rules of thumb, and heuristics (Grigerenzer, 2010, Kahneman, 2003). While it is a plausible claim that bounded rationality is a response to complexity, it has become fashionable for studies on systematic cognitive and behavioural biases to be given as evidence that rationality is bounded and to abjure efforts to understand how systems become complex with novelty production in the first place.

The account of novelty production and evolvability espoused in this paper follows the Hayek (1952) insight and also that of the famous Wolfram-Chomsky schema on Type 4 dynamics[[7]](#footnote-7) (Albin, 1988, Langton, 1990, Casti, 1994, Wolfram, 2002, Markose, 2004, 2005, 2017) as a unique class of dynamics that requires digital/computational systems to embed conditions necessary for Gödel Incompleteness for novelty production.[[8]](#footnote-8) However, it is not till Prokopenko et. al. (2019)[[9]](#footnote-9), and specifically with Markose (2017, 2021a,b, 2022) 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. Genomic intelligence is a concept introduced in Markose (2021a) to characterize the Gödelization of code based genomic information processing and the distinctive self-referential conditions of Gödel Incompleteness results that appear to have been acquired for complexification over the course of evolution of multicellular life, Markose (2022).

In contrast, as noted, almost all proponents of Complexity Economics and those who have examined the Santa Fe Institute and Austrian antecedents of this (see, Fontana, 2010, Bowles et. al. , 2017, Moreno-Casas and Bagus, 2022) place no significance on the computational/digital nature of information processing for complex systems, let alone the Gödel Incompleteness characteristics of genomic information processing that reaches its apogee in humans with complexification and novelty production. Arthur (2015) is an exception in that he does give a nod for the need for Complexity Sciences to acquire what he calls “more algorithmic, more Turingesque; less equation based...” approach.

The paper aims to distinguish between the bounded rationality critique of the Neoclassical model of optimization from a fixed set of actions on the one hand and the strategic necessity to access open-ended search of non-denumerable infinity for adaptive complexity, which is found in the evolution of genomic intelligence, on the other hand. Some new light will be thrown on the relationship between autonomy of organisms and the necessity of such open-ended adaptivity for sustainable life and society governed primarily by the principle of consistency as espoused in classical Kantian style liberalism. While originating from the Cantor Diagonal Lemma and the many steps from epochal results of Gödel (1931), the full developments of Recursive Function Theory (RFT)[[10]](#footnote-10) and the work of Emil Post (1944) will be needed to show how genomic intelligence embeds the conditions necessary to exit from listable sets to produce novel syntactic objects that can be implemented as novel extended phenotypes, to use a term from Dawkins (1987), in the form of artifacts outside of organisms.

The breakthroughs for evidence on the Gödelization of genomic information processing starts with premise mooted by Walker and Davis (2013) on “the algorithmic takeover of biology” with inheritable information being encoded in the genome. Associated with this are the unique identifiers or Gödel numbers for digital entities well known in the digital economy and taking the form of bio-peptide ‘zip codes’ in organisms as discovered in the Nobel prize winning work of Blobel (2009). Two other distinctive Gödelian features found in vertebrate intelligence, using epithets from Hofstadter (1999) are self-reference (**Self-Ref**) or the Diagonal operator and virtual self-representation (**Self-Rep**) with embodied offline mirror mappings necessary for the sentient self. This will be shown to permit complex self-other interaction with the other as a projection of self, which manifests in humans as complex social and adaptive cognition. This initially developed in the Adaptive Immune System (AIS) some 500 million years ago in the lineage of jawed fish and then latterly as Mirror Neuron System (MNS) mostly in primate brains discovered by the Parma Group of neuroscientists ([Fadiga et al. 1995](https://www.sciencedirect.com/science/article/pii/S0303264722001022#bib35); [Gallese et al. 1996](https://www.sciencedirect.com/science/article/pii/S0303264722001022#bib46); [Rizzolatti et al. 1996](https://www.sciencedirect.com/science/article/pii/S0303264722001022#bib102)). The AIS from the get-go implements ‘out of the box’ astronomic anticipative search for novel non-self antigens necessary for novel anti-body production and cognition in humans manifests unbounded proteanism for Dawkins (1987) style novel extended phenotypes in the form of artifacts outside of ourselves. This facility found only in the Adaptive Immune System relies on the Recombination Activator genes (RAG 1 and 2) and in the neuronal diversity of the human brain, runs into orders of magnitude of 1020 – 1030 that exceed the pre-scripted germline genome size many times over.

The most significant of all breakthroughs here is the one made by Binmore (1987) in the context of modelling rational players in Game Theory: Binmore 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” 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, constitutes the *fourth* condition of Gödel systems and involves the agent which represents the formal operation of negation and falsification of what can be computed/predicted. In diverse settings this becomes the model of an adversarial agent whose contrarian[[11]](#footnote-11) actions *a priori* cannot be constrained in any way. In software based digital systems the outputs of machine executable code of algorithms, as in molecular biology and the digital economy, epitomize determinism of computation. In such systems, determinism can be punished by the adversarial agent in the form of viral software, which is coextensive with life itself (Markose, 2021a, 2022). In the earliest instance at the level of molecular biology, genomic information processing first found in the Adaptive Immune System adopted the framework of Gödel Incompleteness in the form of the Gödel Sentence which allows an encoded biotic element to self-report that it has been ‘hacked’ by a novel malware. This marks an endogenous exit from listable sets, a formal condition for novelty, to avoid the irrational state of logical inconsistency. The Nash equilibrium of such an adversarial digital game, missing from the annals of Game Theory, is to produce novelty and surprises in the form of new syntactic objects (like antibodies) or extended phenotypes whilst taking on the structure of an arms race, Markose (2017).

It must be noted that the notion of protean behaviours in biology that manifest as adaptive unpredictability was mooted by Humphries and Driver (1970) after Proteus of Greek mythology who eludes capture by continually and unpredictably changing form. Miller (1997) and Whiten and Bryne (1997) extensively explore competition and courtship in complex social interactions among primates. They make a case for Machiavellian intelligence in primates that can predict conspecific behaviours in order to manipulate each other. Though hamstrung by limitations of extant Game Theory regarding strategic novelty production where indeterminism is confined to randomizing between two known actions, Miller (1997) avers that primate proteanism lead to counterstrategies to evade predictability by generating novelty, surprise and radical uncertainty, which underpin human creative intelligence.

Unbeknown, especially to many an evolutionary economist, Goldenfeld and Woese (2011) have discussed the somewhat pressing need for extant complexity and evolutionary theories to go beyond so-called Neo-Darwinism or Modern Synthesis and take on board advances in gene science and molecular biology in the post Barbara McClintock era. McClintock (1984) Nobel prize winning work on viral software based transposable elements which scissor-paste (transposons) and copy-paste (retrotransposons) is replacing random mutation as the sole driver for evolution. This underscores the truism that primarily only software can change software, rather than random transcription errors. Transposable elements have been found to be instrumental for evolvability and brain plasticity on one hand and malign internal hacking on the other. This implies that new thinking in digital information processing in terms of the 21 st century nomenclature on blockchain distributed ledger (BCDL) is needed to fully understand the significance of novelty production as the consequence of complex strategic adversarial digital games within the ancient precedent of the genomic blockchain distributed regulatory framework which permits novel blocks to be added while life’s protein coding blocks remain immutable and hack-free. The picture that is emerging in the post McClintock era of gene science is of a genomic intelligence in vertebrates that has reached its apogee in humans is one that is

- highly empathic as the conspecific/other is the projection of self by reuse of self-codes in virtual offline mirror systems;

- greatly Machiavellian having co-evolved with adversarial viral agents;

- geared toward unbounded proteanism from the get-go with transposable elements based diversity both in the immune system and neuronal receptors;

-with stringent self-regulation by a unique blockchain distributed ledger driven by the principle of autonomy of the life of the organism and an agenda to be hack free, Markose (2022).

Here, it is important to acknowledge a highly influential position of a leading neuroscientist Karl Friston that purports to underpin the many successes of Narrow and Statistical Artificial Intelligence geared to specific objectives. Friston and co-authors (Friston, 2010, Friston et. al, 2013) rely 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. While this is not without its problems (see, Colombo and Palacios, 2021), Friston 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 by Friston et. al. on the regulatory framework of maintaining homeostasis of life’s vital signs within feasible physical/analogue states, viz. minimizing ‘surprisals’, when this is under the aegis of smart algorithmic controls and must contend with software related data security breaches from bio-malware or adversarial agents. What has been overlooked is that a large part of homeostasis in formalistic code based self-assembly systems of life involves complexification of phenotype with dynamic game structures that have to embrace an arms race in novelty and surprises in order to avoid threats to autonomy from adversarial agents that can hack gene-codes. This is a problem that genomic intelligence appears to have solved. AI in contrast in having ignored this self-referential data integrity for autonomous existence in what is called the ‘sitting duck’ problem, Heaven (2019), makes such systems unsustainable in the wild.

Interestingly, more than other disciplines, in addition to Binmore’s insights, economists have long been alerted to the Gödel logic behind the regulatory problem with adversarial agents in the guise of rule breaking agents who will ‘negate what they can predict’. [[12]](#footnote-12) This is found in the Lucas policy ineffectiveness thesis, followed by the postulate on the necessity of ‘surprise’ strategies in policy to secure policy objectives, Lucas (1972, 1976). Goodhart’s Law (1981)[[13]](#footnote-13) often stated as the dictum that any measure that is made a target of policy becomes a poor measure underscores the demise of formalistic policy targets from actions taken by highly protean regulatees who will game the system. Section 2 starts with the consequences of the flawed macro-economic models that use statistical white noise terms to model novel actions or ‘surprises’ in Economics or worse still that ‘rationality’ within an optimization framework restricts choice of actions from what is already known in order to minimize deviations from a quantitative target. This vitiates horizon scanning for novel adversarial actions and for novel counter responses and has led to disasters in policy design where regulatees are effectively viewed not to break rules and innovate. This blind spot in economic models on human proteanism, with novelty and surprises missing in standard Game Theory, 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 evolvability 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”.  
 In sum, the paper underscores 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. 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 4 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 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 virtual 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 underpin the basis of self in advanced sentient life and permit open ended search for adaptive novelty. In particular, this section will outline how Gödel sentences, far from being an esoteric constructions, are ubiquitous in genomic information processing and can be seen to be a hashing algorithm in the 21century nomenclature. The latter permits an encoded entity to self-report it is under attack or being negated and novelty production is embedded in a blockchain distributed ledger which is preserving of life and autonomy.

The concluding Section 4 of the paper will discuss how there are close parallels between the workings of genomic information processing and the digital economy. Formalistic targets and objectives could run into destabilizing outcomes à la Goodhart’s Law when agents are hitched up to the readily available recursive powers of recombination in digital systems. The latter adduced to be a hall mark of novelty production (Bienhocker, 2011) and 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 blockchain distributed ledger style regulatory frameworks, Nabben (2021), 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 a self-referential blockchain.

**Section 2 Why We Need Digital Foundations of Intelligence for Novelty Production**

In Section 2.1 we start with the problems encountered in mainstream models of modelling novelty or surprise as random shocks, statistical white noise or prediction errors rather than as the consequence of the epistemic capacity to exit from listable action sets for novel extended phenotypes. Sections 2.2 and 2.3 will discuss the main building blocks for the kind of digital systems capable of Wolfram-Chomsky Type 4 dynamics with novelty production found only in biology and via human actions in socio-economic systems. This follows from the Walker and Davis (2013) premise that there was an algorithmic take-over of biology with inheritable information in the genome being encoded in a near universal 4 letter code. This underpins the remarkable fact that in nature only life and biology as we know it and the artifacts of genomic intelligence thereof are explicitly code based digital systems.

***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 modelled 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, in the spirit of Goodhart’s Law, 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 for ‘surprise’ inflation. [[14]](#footnote-14)   
 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, see footnote 14) and sought to reinstate determinism in policy by having the authorities pre-commit to a fixed rule. There is 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.[[15]](#footnote-15) 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 contrarian short selling currency speculators.[[16]](#footnote-16) 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, with no mandate on financial stability, became the mantra of many central banks from about 1994 till the Great Financial Crisis of 2008. Authorities effectively adopted a Theil-Tinbergen style rule regarding the interest rate as the policy variable.[[17]](#footnote-17) 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 being a major example. 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 became a victim of Goodhart’s Law by losing their AAA rating as they took on credit default swap 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 gaming by 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.[[18]](#footnote-18) 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 adversarial digital games mooted by Binmore (1987).

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

|  |  |
| --- | --- |
| **Lucas Postulates on Policy Design** | **Postulates of** **Gödel Logic & Adversarial Digital Games** |
| (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 13. | (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 4 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, abandon horizon scanning for novel adversarial rule breaking and withdrew from the co-evolutionary arms race with regulatees who are left free to ‘arbitrage’ policy. | (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 against novel adversaries and is prepared to go in for co-evolutionary arms race with novel anti-body production. All arms races that register incessant change along one dimension is to maintain status quo along another dimension, mostly life, liberty/autonomy or property. |

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 of life’s vitals 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 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 to any real world phenomena, let alone for the case of machine executable code-based models of cognition. The main reason is that Types 1-3 difference/differential equation-based dynamics in the Wolfram-Chomsky schema is well understood while Type 4 dynamics that arise directly by software operations on code-based systems that requires Recursive Function Theory (RFT) is less familiar. Clearly, far more mathematical logic and RFT than has been used by Hayek and others is needed to fully elucidate how such exit points for novelty are triggered endogenously in certain digital systems. In addition to RFT, new thinking on software data security and decentralized control as in 21 century man made blockchain distributed ledger is needed to show the significance of information processing in the digital genomic systems of advanced eukaryotes that 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.   
 Indeed, as the original Gödel (1931) framework predates the full development of RFT, the Gödel Sentence appears as a funky, esoteric construction of a proposition that asserts its own undecidability that it is neither provable or disprovable. [[19]](#footnote-19) Hamkins(2021) makes an important observation that the original Gödel (1931) framework permits an encodable proposition to make statements about itself while Second Recursion Theorems are needed “to construct programs/algorithms that refer to themselves”. The latter, specifically in the form of the Rogers Fixed Point Theorem (Rogers, 1967) is used in Markose (2017, 2021b, 2022) to generalize the Gödel Sentence for algorithmic dynamics inherent to the adversarial digital game as the fixed point of the negation function of Gödel’s Liar. Further, in Gödel (1931) there is no explicit construction of syntactic objects, viz. the indexes of Gödel Sentences, that lie outside listable sets specifically as in two disjoint recursively enumerable sets, respectively of theorems and known non-theorems. This is achieved by the Emil Post (1944) set theoretic proof of Gödel Incompleteness proof as is an ever extendable set of novel negation functions of digital adversaries (see, also Svahn, 2022). Hence, Markose (2017) has dubbed the formulation of this adversarial digital game theoretic framework as   
**G-T-P** games.   
 Without being exhaustive, two influential strands in the literature either see no bearing of **G-T-P** structures in genomic information processing for complexification or do not take it far enough, respectively, the framework of bounded rationality and the Computational Theory of Mind. It has been indicated that bounded rationality is not a model of open-ended adaptive complexity and neither it nor standard models in decision sciences can give a framework for novelty and surprises other than as random shocks or prediction errors.   
 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 imply a 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 Computation Theory of Mind in Gallistel and King (2010) relating to self-reference (**Self-Ref**) and self-representational (**Self-Rep**) 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 make statements about self or 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).[[20]](#footnote-20)   
 The break through on the significance of these staples of Recursive Function Theory found in textbooks on the subject such as Rogers (1967) and Cutland (1980), starts with the insight that follows from 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 morphology, somatic identity and regulatory control of the organism (see, Tibbits, 2012). Despite the central role assigned to self-reference for the generation of open-ended biological complexity ([Gardenfors 2003](https://scholar.google.se/citations?view_op=view_citation&hl=sv&user=ZW8RWdAAAAAJ&citation_for_view=ZW8RWdAAAAAJ:Y0pCki6q_DkC), [Northoff et. al, 2006](https://doi.org/10.1016/j.neuroimage.2005.12.002) , [Newen (2018)](https://www.sciencedirect.com/science/article/pii/S0303264722001022" \l "bib94) , [Miller et.al., 2018](https://doi.org/10.1016/j.pbiomolbio.2018.10.002)) only Tsuda (2014) and Markose (2021a, 2022 ) directly indicate the relevance of what is effectively the Gödel Meta-Representation Theorem (Rogers,1967) for biotic elements to make statements about themselves having first assembled themselves. The Adaptive Immune System (AIS) demonstrate virtual offline mirrored self-representation (**Self-Rep**) in the MHC1 T cell receptors of the expressed genomic self-assembly codes for the organism to identify malware changes thereof. In turn, the Mirror Neuron System (MNS) reuses codes of self-actions from the sensory-motor cortex for social cognition and inference regarding conspecifics via virtual simulations in the MNS (Gallese, 2009, Gallese and Sinigaglia, 2011). Another important breakthrough (Markose, 2017, 2021a) is to acknowledge that halting self-assembly gene codes that create the somatic identity and phenotype of the organism are theorems of the genomic system. Information processing follows that of formal systems (Smullyan, 1961) governed by the principle of logical consistency in that non-theorems that can negate self-codes can be harmful to the organism.   
 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 somatic and phenotype identity 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 that halts, specifies that a program *m* of a machine constructs 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 and phenotype 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-Rep Notation*** | ***Online Machine Execution  Right Equation (8) (RHS) Self-Ref Notation:*** |
| **Panel A (Left) Medullary Thymus Epithelial cells (**m**-TECs) Mirror Mapping** of tissue specific genes/peptides of ~85% of genome this is expressed | **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,...... gn  Theorems 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 offline mirroring of online motor and sensory cortex activity[[21]](#footnote-21) , **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)[[22]](#footnote-22) , 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 recursive function **Self-Ref**/**Self-Rep** mapping in the above mirror systems as a model of cognition capable of implementing novelty production and reverts back to Types 1-3 mathematics of differential equations for most of his work on neuro-science. In contrast, as will be shown in Section 3, the Second Recursion Theorem of RFT is needed to identify novel negation functions to self-codes as a prelude to novelty production.   
 Detection of negation of what is predicted in the human Mirror Neuron System found in neuro-science experiments by Scott Kelso and co-authors (Tognoli et. al. (2007)) gives evidence for perception of deceit and complex counterfactuals in Theory of Mind in social cognition. Further, similar RAG1 genes found in the immune system (see, Muotri et. al. (2009)) and other transposable elements are known to produce neuronal receptor diversity in the hippocampus for memory and con-specific related social learning and also in other areas of the Central Nervous System ([Chun et. al. 1992](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3436067/#R27), Kaesar and Chun, 2020, Ortiz and Arshavsky,2001).   
 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)[[23]](#footnote-23). 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 information processing in 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 bloc 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 the immune-cognitive aspects of genomic information processing, selective pressures are based on the principles of a blockchain distributed ledger. The main principle of a blockchain 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.   
 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 self-other cognition and novelty production.

***3.1 Cantor Diagonal Lemma, 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.[[24]](#footnote-24) 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, … , which are also listed along the columns. The membership of each set *Wx* is 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, changes 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 (1931) Incompleteness results where the steps were mechanized and conditions given for the constructive production of syntactic objects that lie outside any algorithmically listable set in the spirit of Cantor. However, this awaits 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/digital 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).

The first step in Gödelization starts with Gödel numbers (g.ns) or integers that can bijectively represent encoded information (codes for short) based on a finite alphabet. Recursive or computable functions are 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.[[25]](#footnote-25) 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 the point that the design framework of programmed 3-D self-assembly of digitized materials in 21 century fabrication is one that evolution created the protypes of some 3.5 billion years ago with the self-assembly programs of the ribosome 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, p.123, Rogers, 1967, p.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 index *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* incorporates the index for the undecidable proposition and the total computable strategy functions which are recursive reductions thereof in relation to index *m* will generate novel responses as in the Nash equilibrium surprise strategy functions, Markose (2017). Smullyan (1961, 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.[[26]](#footnote-26) 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 *q* which relates to a specific somatic tissue or phenotype:

 (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 code *g* effectively builds the machine to itself *g.*  The output when ***Diag*** *(g)* = *g(g)*  halts will be applied further in the output of  *q.*

***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*  ***Diag*** *(g)* = *g(g) .* (8)

Here, the diagonal operation of **Self-Ref** on RHS of (7) where a self-assembly program *g* builds machine to run *g* and halts, denoted by *g(g)* , it is bijectively represented in a **Self-Rep** recording as in *s(g,g)* 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)*[[27]](#footnote-27)*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 **Figure 1 Panel B** RHS (right hand side). 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 1 Panel 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.   
 This basal digitized self-assembly 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.

***3.3 The Adversarial Digital Game For Autonomy of Self-Codes of Host***

The focus here is on how the recursive **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 hostile non-self agents. The self-agent will be denoted as the host *(h)* and the non-self agent as the parasite *(p)*, with the two protagonists strictly being confined to using total recursive functions as strategy functions. 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}.* (9)

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).   
 The starting point here is to note that a halting computation is proof by construction. The domain of halting self-referential/Diag machines constitutes theorems in equations (7) and (10), and hence the codes of Theorems in the genomic immune and cognitive systems are, 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*** in (4)(see, Cutland, 1980, p.133). The latter is a listable set of all self-referential machine calculations that halt with any *xℵ* where *ℵ* is the set of integers. Set ***C*** is central to Post (1944) set theoretic proofs for Gödel incompleteness and **Figure 3** 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****} .* (10)

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 3**, ***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. Hence,

***G ●*=***=* ***{****g¬ | g¬ (g ¬) ; TMg¬ (g¬) does not halt ↔g****W****g , g(g)* ***}.*** *(11)*

Representing known members of set ***ℜ*** based on sets ***G*** and ***G●***, defined in (10) and (11), collectively denoted as ***G\*\**,** the g.ns in set ***ℜ - G\*\**** shown in **Figure 3** present non-denumerable infinite number of ways for new technologies or phenotypes that can be formed and hence also the potential malware alterations to gene codes. As noted the objective of the game for the host is to maintain the primacy of the halted self-assembly gene codes that create it in terms of its somatic and phenotype identity in (10), which it has self-repped as its theorems in **Figure 3 (in green)** and avoid logical inconsistency from functions that implement negations of these theorems. This game does not have a scalar objective function like a utility function or a fitness function well known in standard Game Theory.   
 What is important to note is that the list of forbidden codes or genomic non-theorems cannot be exhaustively listed in the set ***G****●*= ** in (11) and **Figure 3**. If the non-self adversary *p*  uses a known bio-malware function, *fp¬* with g.n number *m¬* on some gene code, *g,* with its composite g.n denoted by say *gn-1¬* , belongs to the *n-1*  enumeration in the set ** , and this will trigger previously generated antibodies by the host. Note strategy functions *fi* , *i(h,p)* which produce novelty and surprise will in general be denoted with the superscript exclamation mark ! and their g.ns must belong to the set ***ℜ****-****G\*\****, :  
 *fi = fi!= m* , such that *m ∈* ***ℜ****-****G\*\****, *i (h,p)* . (12)

**Figure 2** **Set *ℜ of ‘technologies’ is not recursively listable*** *: “***Think Outside Box”**  ***A surprise strategy is an innovation*** *fi* ***=*** *fi!* ***=*** *m* *,**m****∈ ℜ*** *-****G\*\*****,*

Set R of Total Computable Functions representing all possible technologies: non-denumerable   
infinity and not recursively enumerable

***Novelty and Surprises : Encoding of strategies that lie in (R - G\*\*)***

***Outside the box***

***G****\*\** Subset of R Contains known technologies   
**‘The Box’**

The listable set ***G****● =* **is a subset of the set ***C~*** in equation (5) and shown in **Figure 3** andhas the property explained in Markose (2017) **Lemma 3** and **Lemma 4**, that its index *n¬* entails a recursive enumeration function *( Diag(gn¬)* *)= n¬* such that nth element *n¬* of the enumeration of what will be shown to be the Fixed Point given by *Diag(gn¬)* for a novel bio-malware negation function, denoted by *fp¬!,* also called the Gödel Sentence, can only be added to the listable set **, but, cannot belong to **. Thus, *n¬∉* ***C*** *∪*  as shown in **Figure 3** is neither provable or disprovable as is required of the Gödel undecidable proposition and Gödel Incompleteness. The Nash equilibrium strategy for the host, given *n¬*  can only be a novel surprise one denoted by *fp!*  and it is a recursive reduction as shown in Figure 3 which will exactly map the set theoretic properties of *n¬* and constitute novel activities aimed at preserving the Theorems in set ***G***.

**Figure 3 Gödel Incompleteness Result in Miniature: An Illustration of Mirror Mapping in Thymus Medulla of Gene Codes that are Theorems in Genomic System (Green) And Novel Anti-body Generation As A Blockchain**Gödel undecidable proposition *sn¬*lies outside the listable sets ***G*** and , viz. *n¬∉****G*** *∪*. Note  
*sn¬= t (Diag(gn¬)* ).



*fh! ( n¬)* =

Novel Antibody Generation ( *fh! ( sn¬)* ) in a Productive Set, Post (1944): Blockchain   
Red Arrow shows the strategy function of host is a **recursive reduction** with the same set theoretic properties of sn¬ arising from the Gödel Sentence

***3.4 Gödel Sentence for Liar Strategy/Malware Detection and Genomic G-T-P Model for   
Blockchain Distributed Ledger***

It is well known and shown in Markose (2017) that for digital systems for which the **Self Rep** mapping in (8) is in place, the Roger Second Recursion Theorem can kick in for the construction of the fixed point of a total computable function that alters the code *g* and transforms halting ***Diag****(g)* outputs. The complication here is that the host is confronted by adversarial negator who can use *fp ¬!* that belongs to a non-denumerable infinite set *R*  in (9) and **Figure 2**. Markose (2021) has modelled the immune system of the host to be generating via the V(D)J recombination operators on self-repped gene codes an astronomic numbers 1020 -1030 of encodings of (*fp ¬!* , *g* }, *g * ***G*** pairs. This is a most spectacular form of offline predictive coding by the immuno cognitive system to determine the fixed point of yet to happen novel bio-malware attacks that occur in the periphery in real time. As will be seen, if and when the attack takes place in periphery involving the specific pair *{ fp*¬! , *gn* }, the experientially driven peripheral MHC1 receptor must record this and if this ‘syncs’ with the one that was speculatively generated in the thymic T-cell receptors, two parts of the fixed point come together and there is a genomic Gödel Sentence for the host.   
 The so called Liar/Malware Strategy is stated as follows in equation (12.a). The Liar strategy or bio-malware *fp*¬! can successfully hijack the ***Diag*** *(gn )* self-assembly machine of the host and make it do in a halting machine execution highlighted in (12.b) the opposite of what the host has recorded as its somatic or phenotype output of *q* on the RHS of (12.a).

**The Liar/ Malware Strategy** *fp*¬ !

=¬ *q¬**iff q*. (12.a)

= *fp*¬ !*Diag (gn)*. (12.b)

In (12.a), the effect of taking the machine execution of the malware altered gene code *gn¬* with input *gn*, viz.  is to change the output of halting self-assembly machine *Diag (g­n)* = (on the R.HS of (12.a)) in the following way : we have ¬ *q¬* if and only if  *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  
*s* (*gn¬*, *gn*) in the second term on the LHS in (12.a) 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¬, gn)* 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 *gn* and 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 have motifs such as s (*gn¬, gn¬)* for the fixed point for the novel *fp*¬ ! attack on gene code *gn,* 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¬, gn)* 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 with respect to some *gn*. Thus, Rogers Fixed Point Theorem (1967, Section 11.2) states that any total computable function, *fp¬!*, for the case in question, has as its fixed point an index given by an integer *v* such that *(s)* (*s*), viz. either both sides are defined and are equal or else both sides are undefined.

**The Gödel Sentence**:

*(s)*   *(s)*  (*s*). (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¬!*, *gn*) pair. Further, by construction, the index *v*  is not of a computable fixed point as it will produce a contradiction,[[28]](#footnote-28)and hence in (13) the outcome 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) construction of the productive set in **Figure 3** follows in that the enumeration index for *Diag(gn¬)gn¬, 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.[[29]](#footnote-29)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.[[30]](#footnote-30) 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 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 3,** 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 3** , 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 3**, 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 blockchain distributed ledger principle for the digitally controlled homeostasis for the eukaryote genomic system lies in the fact that the series of Gödel Sentences will flag out the 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 disjoint recursively enumerable of Theorems and known non-theorems of the genomic system given in **Figure 3**. 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[[31]](#footnote-31) 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 of 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-based and formalistic systems which represent determinism is vulnerable to being hacked by adversarial, often viral agents, who Binmore calls Gödel’s Liar. This results in the impossibility of restricting the activity of biotic malware 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 blockchain 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** adversarial 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 blockchain distributed ledger technology shown in **Figure 3** 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 and phenotypic self-identity whether in the Thymus or in the brain. There is strong evidence the immune-cognitive systems in vertebrates and latterly in the human brain have capacity for accessing open ended adaptive complexity and novelty production which is distinctively missing from models of bounded rationality and Neoclassical optimization models.   
 This brings us to the problems of targets and objectives which can be gamed by protean agents as famously stated in Goodharts Law. 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. Centrally dictated objectives can be enforced only if potential rule breaking is eliminated.   
 The genomic 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. But this is done strictly for the preservation of life and the autonomy of organisms to be hack-free. Where the Liar/pathogen cannot be eliminated, the genomic 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 already noted, as extant game theory is silent about such ubiquitous activities, this is also missing in any discussion about policy design in mainstream economics.   
 Externally set targets could imply 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[[32]](#footnote-32) (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 in a paperclip apocalypse. 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** blockchain DLT of the eukaryote genomic system appears to show 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 (see, Nabben, 2021). Again the unique nature of blockchain DLT in genomic systems was first pointed out by Abramov et. al. (2021) 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 a self-referential genomic intelligence which AI is unlikely to achieve as its design principles have insufficient attention to autonomy, are still too reliant on target driven formulations and statistical models for novelty.

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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. [↑](#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. Klimek et. al (2012) have developed a framework for measuring creative destruction in economies. [↑](#footnote-ref-5)
6. Koppl (2006, 2009) is known to have propagated the view that the Hayek-Gödel epistemic incompleteness problem is equivalent to the Herbert Simon notion of bounded rationality. [↑](#footnote-ref-6)
7. Dynamics of Types 1-3 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 such non-linearity is the pinnacle of complex dynamics. [↑](#footnote-ref-7)
8. This is over and above the often-stated condition of computational universality for complexification (see, Del le Cuevas, 2020) as found in computing machinery such as Neural Networks or Rule 110 of Cellular Automata which can simulate any other general computation. [↑](#footnote-ref-8)
9. 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-9)
10. General recursive functions or computable functions are number theoretic functions involving finite steps of instructions, called an algorithm or a program, operating on integers, aka Gödel numbers, 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,logical 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) and use Computation Theory and Recursive Function Theory synonymously. [↑](#footnote-ref-10)
11. Markose (2021b) has discussed the significance of contrarian agents and the insight of Arthur ( ) on Minority or El Farol games in which superior payoffs follow when an agent plays a contrarian strategy that places him/her in a minority. [↑](#footnote-ref-11)
12. The reader is directed to Markose (2021,c) Essex University Blog for an informal discussion of the Binmore (1987) critique of Game Theory and how my training as an economist paved 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-12)
13. 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-13)
14. 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-14)
15. 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-15)
16. 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-16)
17. 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-17)
18. Lucas (1976) 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-18)
19. 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-19)
20. Rescorla (2020) summarizes this unfortunate state of affairs saying “There is wide consensus that the criticism of 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-20)
21. 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-21)
22. 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-22)
23. 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-23)
24. 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 along the lines of Cantor Diagonal Lemma was first mooted in Hayek (1952). However, far more machinery and evidence have to be given to substantiate this claim. [↑](#footnote-ref-24)
25. 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-25)
26. 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. Also note, it is beyond the scope of this paper to given a full model of gene expression. [↑](#footnote-ref-26)
27. 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-27)
28. On updating (12.a) and (12.b) the Liar/Malware strategy *gn¬* now operates on itself, we have =  , which is a contradiction. [↑](#footnote-ref-28)
29. 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-29)
30. 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 (13), 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-30)
31. 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-31)
32. 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 and the sitting duck problem (see, Heaven, (2019)). [↑](#footnote-ref-32)