# TGD view of Michael Levin's work

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## Contents

**Abstract**

In this chapter, I will discuss the findings of Michael Levin's group related to morphogenesis and also the general ideas inspired by this work. The findings demonstrate that the hypothesis that genotype fixes the phenotype apart from adaptations is wrong. Already epigenesis challenges genetic determinism and the view emerging from the experiments is that the patterns of membrane potentials of cells of early embryo determine patterns of electric fields in multicellular length scales and that code for the outcome of the morphogenesis. One can say that these patterns code for the goal directed behavior and have the basic properties of memory. The manipulations of these patterns in the early embryonic stage can modify the outcome of the morphogenesis so that one can speak of a novel organism. Also the manipulations of say gut cells can produce organs such as ectopic eye.

One can regard multicellular systems as predecessors of neural systems. Ion channels and pumps are present in both systems. In nervous systems synaptic contacts replace the gap junctions. Nerve pulse patterns are replaced by waves associated with gap-junction connected multicellular systems.

Levin introduces notions like cognition, intelligence and self not usually used in the description of morphogenesis and represents a vision about medical applications of the new view

The TGD view of morphogenesis is compared with Levin's vision. The basic picture relies on the notions of magnetic and electric bodies, to the phases of ordinary matter with effective Planck constant $h_{eff} = nh_0$ behaving like dark matter and making possible macroscopic quantum coherence, and to zero energy ontology (ZEO) providing a quantum measurement theory free of the basic paradox. ZEO is implied by almost deterministic holography forced by general coordinate invariance. Holography implies that structure is almost equivalent to function.

This framework explains the basic finding that the goal of the morphogenesis is determined by the patterns of electric fields during the early embryo period. TGD also suggests the universality of the genetic code and several variants of the genetic code. Morphogenetic code might reduce to a variant of genetic code realized by cell membranes and larger structures instead of ordinary DNA. TGD predicts the analog of nerve pulse with the increment of membrane potential in mV range. These patterns would play a key role also in neural systems.

# 1 Introduction

This article was inspired by the work of Michael Levin's group in biology. I have already earlier (2014) commented the work of Levin [I7, I8, I15] in the article [L1]. To my view, these discoveries profoundly modify the views of the role of genes and lead to a completely new vision about morphogenesis about which genetics cannot tell much.

The amazing discoveries by Michael Levin and others related to morphogenesis (such as the discovery of xenobots as synthetic life forms) could lead to the correct track not only in biology and neuroscience but also in attempts to define and construct AI and artificial life.

The articles [I9, I11, I6, I2, I5, I10] provide a good view of the vision of Levin. Interested readers can listen the interviews and talks of Levin in web.

I started with the interview of Michael Levin at `https://youtu.be/XheAMrS8Q1` with title "The electrical blueprints that orchestrate life" . The talk "Plasticity without genetic change: bioelectric embryos & synthetic proto-organisms" (`https://www.youtube.com/watch?v=5ChRM4CEWyg`) gives a summary of the role of bioelectricity in embryos and about the synthesis of artificial organisms known as xenobots.

The talk "Understanding the Collective Intelligence of Cells: bioelectrical navigation of anatomical morphospace" at (`https://www.youtube.com/watch?v=jLiHLDrOTW8` provides a view of morphogenesis as a navigation in morphospace towards the final morphology as a goal represented as a memory.

The talk of Josh Bongard titled "A xither of xenobots: demolishing dichotomous thinking with synthetic proto-organisms" (`https://www.youtube.com/watch?v=7EA2AqSO5tQ` discusses the implications of the findings for fields like AI. The talk is about brain/body -, genotype/phenotype -, and tape/machine dichotomies, which have made a real progress in ortodox AI difficult, if not impossible. The article [I5] discusses the same topics.

The approach of Michael Levin does not mention quantum biology at all. At least from the perspective provided by the TGD inspired view of quantum physics and quantum biology, the

findings are however extremely inspiring. In the sequel, I will discuss these findings and the theoretical vision inspired by them, and also the interpretation of findings in the framework of TGD inspired theory of consciousness and of quantum biology. These findings provide crucially important bits of data for a further development of the already existing TGD view of morphogenesis [L1, L18, L14, L13]. Also the interpretation of the zero energy ontology (ZEO) [L7] becomes more precise.

## 1.1 About the basic vision and experimental findings of Michael Levin

The basic challenge is to understand how organisms evolve from embryo to their final shape. Genetics applies at the level of a single cell and does not offer clues of how genes might determine the shape and size of the organism. Therefore the dogma that genotype determines phenotype has remained an unproven hypothesis. Already the emergence of epigenetics has made clear that genes are not enough: the same genome has very many transcriptions, which can vary in a very rapid time scale for a given organism. The work of Levin's group has shown that the correspondence between genotype and phenotype is even more flexible: one can even create new life forms using a given genome (zenobots).

### 1.1.1 Does bioelectricity code for morphogenesis?

The underlying idea is that the dynamics of the brain as a collective of neurons has evolved from the morphogenesis of cell groups. Instead of a communication using nerve pulses patterns, the communications use the distribution of membrane potentials (hyperpolarization and depolarization). Static gap junctions in turn take the role of much more dynamic synaptic contacts.

1. Dynamical patterns of membrane voltages assignable to cell membranes, which are determined by the voltages assignable to voltage gated ion channels and pumps, connectivity of cell groups determined by the distribution of gap junctions, plus long range potential gradients controllable by the patterns of membrane potentials, seem to act as a new control level which also controls the epigenetic level. The membrane voltage pattern and distribution of gap junctions are controlled in the experiments of Levin's group using biochemical tools.

2. The potential gradients in the scale of the organism or organ associated with the embryo in turn determine the morphogenetic goal as an analogue of memory in the same way as voltage gradients correlate with the state of the brain.

3. Electric signals as oscillation patterns of membrane potentials between cells mediated via gap junctions are proposed to actualize an analog of a computer program. This signalling is also referred to as conversation, which would be something less deterministic. The program would code the destiny of the cell group.

4. Self-organization in some sense is involved. Dissipation takes care that self-organization leads to a very few final states from a larger number of initial states. It is not however clear whether biological self-organization can be described by the standard picture in which self-organizing dissipates incoming energy and ends up to a thermal non-equilibrium. Related question concerns homeostasis: how is the system able to stay near a critical state, which is by definition unstable? Here self-organized criticality is a suggestive notion and to my best understanding not very well-defined.

### 1.1.2 Some astonishing findings

Manipulation of gap junction distributions and very specific ion channels has led to a handful of very astonishing findings providing deep insights of the basic mechanism of morphogenesis.

1. Planarians are animals which create offspring by replicating. They can be split even to 200 pieces cuch that every piece develops to a full-grown planarian. One might say that planarians do not experience aging at all. Long length scale electrical gradient rather than genome determines the positions of head and tail. Knowing also when to stop the growth is

very important. How this is realized is not understood. Does the morphology of an adult planarian have a representation serving as a template in growth?

It is possible to manipulate the ion channels and gap junctions such that electrical field configuration changes and the split planarian develops to two planarians having two heads. This feature is preserved in further splittings of the planaria.

Also the memories of the parent planarian (defined as behavioral patterns) are inherited by the daughter planarians. The development of larva to a butterfly is a second example. The phenotype and also the brain of the larva are dramatically changed in the transition but the memories of the larva are preserved. This suggests that the memories are not presented at the level of the brain.

2. The gut cells of frogs, whose membrane potentials and gap junctions have been appropriately manipulated to give rise to long range electric gradients, can generate a functioning ectopic eye located outside the head. Also other organs, even those usually bot possessed by frog, can be generated in this way.

3. In Picasso frogs the embryo is mixed so that various parts of the embryo are in the wrong places. The embryo however develops into a normal frog. Therefore morphogenesis cannot be a hardwired set of movements. There is minimization of error and goal directed behavior.

   Computer scientists would talk of a computation determining the large scale anatomy, with computation interpreted as a search of the goal configuration in morphospace and represented as a stable memory. Conscious theorists would talk of a goal directed behavior as intentional behavior.

4. Xenobots are a completely novel life form evolving from appropriately manipulated frog embryos involving removal of a fraction of cells. Genetically unaltered cells coalesce and are liberated from the rest of the body. Novel bodies are different from tadpoles and epigenesis is different. For instance, cilia have a different function. In the frog, they transfer the mucus whereas xenobot uses the cilia for swimming.

## 1.2 Giving up genetic determinism

The basic belief is that genotype determines the phenotype. Only adaptations can change the phenotype. Programming by machine code serves as a metaphor. The computer itself is modified in the programming. The emergence of computer languages meant a revolution and information science was born. There was no need to modify the hardware anymore. Computer programs, represented as input signals, defined the computation. Only the simplest functions are realized as programs at the level of hardware and their functional composition gives rise to programs in accordance with the Turing paradigm.

One can say that most of the recent biology studies only the machine code level. Genes code for the basic building bricks (proteins). Biological systems would be like computers determined by the genetic code. Genetic determinism reflects this belief. This approach leaves open how the behaviors analogous to running computer programs emerge. Machine code metaphor would suggest they are determined completely by the hardware, genes.

The revolutionary idea is that there exists an analog of higher level computer languages based on electric fields. Bio-electric programs would correspond to electrical signalling. Morphology would be based on patterns of electric voltages assignable to cell membranes determining potential gradients in longer scales. For the early embryo these gradients would code for the morphology.

The examples mentioned in the introduction allow us to deduce conclusions of this programming.

1. The morphology of an adult planarian is coded by the long scale electric fields of the embryo. Also the memories interpreted as behaviors are inherited in the replication of planarians by splitting. This means that the morphogenesis is goal directed and goal corresponds to a stable memory.

   If the long range potential pattern of adult planarian is manipulated to produce 2-headed planarian after the splitting, the planarian is not affected. Therefore one can say that the

memory of the electric field pattern matters but that in the splitting the memory is replaced by a new one. Also the descendants of split planarians have two heads so the memories are inherited in splitting.

2. The example of Picasso frog tells that even dramatic perturbations are not able to prevent the development towards a correct goal. Goal is indeed a stable memory coded by the electric state of an early embryo and the system is able to make error corrections.

3. The gut cells or frogs, when appropriately manipulated to modify the connectivity determined by gap junctions and the long range electric fields can develop to ectopic eye. Also other organs can be generated in this way. Even organs not usually possessed by planarians, such as fish fins, can be generated. Xenobots are novel life forms with the same genome as the frog.

   These findings imply that the memory telling the goal can be rewritten and does not depend on gene expression. The same genome corresponds to the entire morphospace consisting of different organisms with different functions. Epigenetic level is however differently realized.

These findings are consistent with the proposal that goal is represented as a memory which is characterized by long-term stability, lability (rewritability), latency (conditional recall: the 2-headed planaria is generated only if the planarian is gut first), and discrete set of possible outcomes.

This inspires the computational hypothesis. Goal is computed. Electric signalling and classical long range potential gradients define an analog of genetic code and one can wonder whether some kind of morphic code based on the grading of the membrane potential exists. Difficult questions relate to the realization of the memory. How it can be stable if the organism itself is evolving. Some kind of time travel would be required for memory recall. Is it a conscious memory?

## 1.3 Xenobots challenge the dichotomous thinking in biology and AI

The talk of Josh Bongard having title "A xither of xenobots: demolishing dichotomous thinking with synthetic proto-organisms" (`https://www.youtube.com/watch?v=7EA2AqSO5tQ` discusses the implications of the findings of Levin's group for fields like AI. The topic of the talk are brain/body -, genotype/phenotype -, and tape/machine dichotomies, which, according to Bongard, have made a real progress in ortodox AI difficult, if not impossible.

1. Brain/body dichotomy states that the brain tells the body how to move. In this picture, the body is a dead robot, hardware, and the conscious brain is the central intelligence, the software, which determines how the body moves. This view has dominated the view about AI. Although this view is plagued by several paradoxes due to the fact that nerve pulse transmission is quite too slow to realize the multiple feedback needed to actualize the commands of the brain, it still dominates the thinking.

   The talk illustrates the basic failure of robotics by videos of falling robots. This illustrates the basic difference between robots and living matter. Humans do not fall down although they are about to fall down all the time. This is because of homeostasis. Living matter is a critical system which by some mechanism is able to remain near the criticality. Robots are not such systems and they fall down.

   Biology suggests how to make this view more realistic by assuming that both the brain, software and the hardware can adapt. For rigid robots only the brain adapts. The talk describes smooth robots whose shape can vary. The challenge is to have a moving robot and a genetic algorithm indeed allows to find brain/body adaptation strategies. The genetic algorithm indeed discovers unexpected strategy in a situation making movement possible. Brain actually adapts very little for the model considered.

2. Genotype/phenotype dichotomy more or less equivalent with genetic determinism states that genotype determines phenotype. Epigenesis means the failure of the strictest form of this dichotomy. Xenobots mean much more dramatic failure. Same genome can give rise to different organisms.

   AI has played an important role in the development of the Xenobots and a simple in silico model of the xenobot consisting of skin tissue and muscle tissue is discussed. In this model

skin selves receive impulses from random actions of motor parts and are able to generate coherent motion. How this happens looks like a mystery. The mystery is much deeper: how selfish cells having only personal goals are able to transform to unselfish parts of an organism. This remains one of the deepest challenges of biology and the notion of emergence remains only a magic word without actual content.

3. Tape/machine dichotomy is central in computer science. Turing machine serves a a mathematical model of computer. Tape would represent the program and the machine would produce from the input table the output buble. Self-replication machines are Turing machines able to replicate. The talk represents a simple model for von Neumann self-replicator, which consists of 4 parts A,B,C, and D representing the tap. A makes a copy of A+B+C and B then makes the copy of D and combines A+B+C and D together. This kind of self-replication is called kinematic self-replication.

   In living matter this dichotomy is far from obvious although the notions of input as a generalized sensory percept and output as motor action make sense. In living matter the self-replication is very different and takes place by growing. There is no obvious identification of tape and machine.

   Xenobots represent a biological actualization of a kinematic self-replication. Few generations of xenobots are possible. Genetic algorithm has been used to develop a simulation of self-replicating xenobots.

## 1.4 Brief comparison of Levin's views with the TGD view

Despite very different starting points, there are many similarities between Levin's views and TGD view.

1. Levin emphasizes the importance of cognition and also introduces the notion of self. Levin also talks of collective intelligence (swarm intelligence) and cognition and argues that all intelligence is basically collective intelligence.

   TGD inspired quantum theory of consciousness predicts self hierarchy. In the TGD framework, number theoretic physics involving p-adic and adelic physics provides a mathematical framework for the description of cognition. One can say that number theory becomes part of physics. $M^8 - H$ duality would actualize the duality between the view about physics as geometry and physics as number theory.

   One of the predictions is hierarchy of Planck constants identifiable as dimensions of algebraic extensions of rationals assignable to polynomials of real argument, which define space-time surfaces by $M^8 - H$ duality. This number theoretic holography involves almost deterministic holography at space-time level implying in biology an almost exact structure-function duality. Once one knows the 3-D surface, the 4-D space-time surface is almost uniquely determined as an analogue .bvcx of Bohr orbit.

   Number theoretic vision leads also to a universal mechanism for the formation of bound states, which would also describe the formation of quantum coherent units from parts, such as selfish cells.

2. The experiments of Levin's group demonstrate the failure of genetic determinism and genetic reductionism. For a given genome one can have a large number of very different phenotypes involving different epigenomes. Genes would be only a hardware or lowest level of biological scale hierarchy and higher levels would control the lower levels rather than being determined by the gene level. Examples are genetic level, transcriptional level (epigenesis), morphogenetic level, physiological level, neurological level, and even higher levels. Multiscale competency is the term used by Levin. This means self-organization and slaving hierarchies.

   In TGD these hierarchies correspond to fractal hierarchies of space-time sheets (MBs and EBs), p-adic length scale hierarchies, hierarchy of effective Planck constants labelling dark phases of ordinary matter, various algebraic hierarchies for symmetry algebras associated with TGD, to the hierarchies of inclusions of extensions of rationals, to the hierarchies of hyperfinite factors of type $II_1$, and self hierarchies as hierarchies of conscious entities, selves.

3. Levin proposes electric coding of morphogenesis based on membrane resting potentials and that gap junctions connecting cells to each other give rise to connected morphogenetic units. For instance, cancer cell population would disconnect from the population. Furthermore electric signalling between cells based on membrane oscillations would be essential for morphogenesis.

   TGD suggests that ordinary genetic code is only a special case. The genetic code is universal and there is a hierarchy of realization of genetic code. One fundamental realization of the genetic code would be in terms of so-called icosa-tetrahedral tessellation of $H^3$ [L10] and it would induce various realizations at the space-time level. Dark genes would provide 1-D realization and cell membranes might provide 2-D realization of the genetic code and even 3-D realizations can be considered.

   Realizations of genetic code in terms of dark proton sequences with codon realized as dark proton triplet and dark photon sequences with codon realized as dark photon triplet are predicted.

   In TGD, cell membranes correspond to electric bodies (EBs) and the proposal is that they act as Josephson junction communicating with the magnetic body (MB) using dark Josephson radiation and a cyclotron resonance mechanism transforming frequency modulated Josephson radiation to a sequence of pulses. Besides ordinary nerve pulse patterns, patterns of pulses in mV scale assignable to gap junction connected cell groups are predicted [L14] inspired by the experimental work of Prakash et al [I14, I12, I13] and Adamatsky [I1] and the TGD view of quantum gravitation [L13] predicting that quantum gravitational coherence is possible in arbitrarily long scales and is especially important in quantum biology.

4. The notion of morphospace corresponds in the TGD framework to the "world of classical worlds" (WCW) [K1] [L11, L19], which in the number theoretic vision has unique number theoretic discretization using appropriate extension of rationals.

5. In TGD, the notion of cognitive light-cone introduced by Levin corresponds to causal diamond (CD) [L7, L12] [K2], which is the basic notion in zero energy ontology (ZEO) providing a new ontology of quantum theory solving the basic paradox of quantum measurement theory. CDs form a fractal hierarchy.

Consider now the basic differences.

The basic difference is that Levin does not mention quantum theory at all. In the TGD framework, quantum theory is based on ZEO [K2] rather than the standard ontology of quantum mechanics, which relies on the identification of subjective time and geometric time of physicists. ZEO has rather non-trivial implications such as the prediction that in the ordinary state function reductions (SFRs) the arrow of time changes. These implications are crucial for understanding consciousness and biological self-organization. The views of free will and consciousness are different. Levin suggests what he calls a technological approach to Mind [I10]. The engineering based approach is proposed to lead to the notion of self, to explain cognition, and also even free will as an illusion, and perhaps even consciousness. Self would be determined by the morphogenetic or some other goal, and would be in principle an experimentally testable notion. Levin assumes that cognition is universal and appears in all scales. Also in TGD cognition is fundamental and number theoretical physics (adelic physics) [L3, L4] is needed to describe the mathematical correlates of cognition. This leads to the view the physics as geometry and physics as number theory are complementary descriptions of physics [L8, L9, L19, L17] The ZEO based quantum measurement theory extends to a theory of consciousness. In the TGD framework, Sslf as it is identified by Levin, would correspond to the unchanging part of self, kind of "soul". Self is predicted to also have a changing part determined by the generalized sensory input and motor actions. The unchanging part of self would by holography serve as a memory dictating the goal of the evolution of self, in particular in morphogenesis.

**Note**: I give the references to the articles related to TGD, which appear at my homepage. The articles have been published also in the journals founded by Huping Hu (PSTJ, JCER, and DNADJ) and the list of the published articles can be found at my homepage (`https://www.tgdtheory.fi/`

tgdmaterials/curri.html). The reason is that the articles at homepage are updated versions of original ones.

# 2 Levin's vision

In the following I try to summarize Levin's view of cognition and the big vision about implications of the new view of morphogenesis. The articles [I9, I11, I6, I2, I5, I10] provide a good view of the vision of Levin. The interviews and talks of Levin provide the best way to get a view of Levin's vision and the following only tries to summarize the most important points. The following interviews and talks provide a good overall view of Levin's work.

- The electrical blueprints that orchestrate life (https://youtu.be/XheAMrS8Q1c)
- Plasticity without genetic change: bioelectric embryos & synthetic proto-organisms (https://www.youtube.com/watch?v=5ChRM4CEWyg)
- Understanding the Collective Intelligence of Cells: bioelectrical navigation of anatomical morphospace (https://www.youtube.com/watch?v=jLiHLDrOTW8)
- Biology, Life, Aliens, Evolution, Embryogenesis & Xenobots (https://www.youtube.com/watch?v=p3lsYlod5OU)

## 2.1 Technological approach to Mind

Levin proposes what he calls a technological approach to mind [I10]. Levin suggests an active engineering approach in which new structures are constructed and studied instead of a passive study of existing structures.

1. Levin suggests definitions for the notions of cognition, intelligence [I11, I6] and of self [I9]. It remains unclear to me whether cognition is assumed to involve consciousness.

   (a) There would be no privileged substrate of cognition. This might be taken to mean that cognition is something universal. This also suggests panpsychism.

   (b) Intelligence is identified as the ability to solve problems in abstract spaces.The abstract spaces correspond to spaces of possible goals of the system in various scales and form a hierarchy. Problem solving means achieving a goal in the space considered. The same goal achieved by different means: this would be the basic characteristic of intelligence.

   Ordinary 3-space, morphospace and physiological represent basic examples of spaces. One can also talk of genetic and transcriptional spaces. The goal space at a given level can "bend" the space at the lower level so that the agents at the lower level start to collaborate instead of behaving in a selfish manner. In organisms, selfish genes become unselfish. In cancer just the opposite happens and means that the cancer cells as a subsystem quite concretely separate from the system.

   (c) Somewhat cryptically, the notion of self is identified as boundaries of goals that the system is capable of pursuing. More concretely, one might also say that the developmental goal of the organ or organism assigns self to it.

2. Developmental bioelectricity is another key notion. It is identified as a phylogenetic precursor of brain dynamics, a physiological medium for the software of life, and a medium of the cognition of morphogenetic swarm intelligence of cells. All intelligence is basically collective intelligence in which the subsystems start to collaborate to reach the collective goal.

3. Evolution would be greatly potentiated by multi-scale competency architecture [I2]. Evolutionary step would not be finding a solution to a problem but building a new kind of machine solving more complex problems. Increase of the scale and emergence of a new evolutionary level would be in question.

Selection by evolutionary pressures and random mutations drive the evolution in the Darwinian view. Levin expresses his view by saying: "where the goals come from, if not from selection?". One can of course ask whether the increase of complexity closely related to intelligence is a basic evolutionary goal of the Universe. This view seems to be in conflict with the second law however.

## 2.2 Levin's view of cognition

### 2.2.1 Multiscale competency architecture

Multiscale competency [I2] architecture is a key notion used by Levin.

1. Evolution uses multi-scale competency architecture to evolve machines that solve problems. The meaning of machine is however different from that in the recent technology [I5]. One could translate "multi-scale competency architecture" to a fractal slaving hierarchy in which higher levels whose dynamics is in longer spatial and length scales interact with lover levels and receive information from these levels and control them.

   Scaling is a key aspect of evolution. Evolution step means the emergence of a system characterized by larger spatial and temporal scales of coherence and of higher complexity and consisting of the already evolved systems, which start to co-operate. The spans of memory and anticipation increase.

2. DNA specifies cellular hardware but is controlled by agential materials inducing different epigenetic patterns.

3. Dynamics is robust due to anatomical homeostasis. Morphogenesis can be seen as an intelligent behavior of a cellular collective solving problems in anatomical morphospace. Computationalist would say that problem solving reduces to a search in the morphospace in order to reach a goal.

4. The cognitive glue that harnesses cells towards large scale outcomes ("bends" the lower levels to collaborate) is developmental bioelectricity. Goals are represented by long scale electric patterns generated in the embryonic stage and are identifiable as pattern memories utilized by collective intelligence of the organ. The experimental work of Levin et al makes it possible to read and write pattern memories.

### 2.2.2 Collective intelligence of cells

`https://www.youtube.com/watch?v=jLiHLDrOTW8`

Usually one distinguishes between centralized intelligence (brain would be the basic example) and collective/distributed/swarm intelligence. Levin proposes that all intelligence is collective intelligence.

The proposed multiscale competency [I2] in which higher level "bends" lower levels to co-operate, could be translated as a slaving hierarchy involving "bosses". One can also speak of a nested cognition.

There is a high multiscale competency already at the level of a single cell and in this case the smaller subunits are subsystems of the cell down to the level of genes. Single cell morphology and behavior are indeed very complex. The cell can detect bodies in its environment by generating vibrations which are reflected from objects. Kind of sonar is in question and allows us to build a map of the environment. The cell is able to reach the desired targets of the environment using this information.

Levin lists the following key aspects of collective intelligence.

1. Navigation in morphospace towards the goal and multiscale competency architecture (slaving hierarchy) makes this possible. Higher level morphospaces "bend" the lower level morphospaces forcing them to collaborate.

2. Goal-directedness involves recognizing, building, and controlling and communicating with agents in possibly unconventional embodiments (non-standard phenotypes). Self is defined as a cognitive boundary identified as the goal of the system.

3. Anatomical control reflects the collective intelligence of cells navigating in the morphospace. Bioelectric networks and their proto-cognitive medium (ancestor of brain function) → impact on biomedicine. The term "proto-cognitive" suggests that ordinary cells are not assumed to cognize. The goal of an organ or organism is coded by the electric field patterns during early embryo stage and can be regarded as a memory.

4. Synthetic bioengineering as a construction of new bodies and new minds corresponds to the active, engineering aspect of the approach. What is new and racial is that the novel organism does the job itself when the goal is given.

   The novel life forms have no evolution behind them and their possibility suggests that same genomes can give rise to widely different organisms and that also different life forms can give rise to similar organisms. This view forces us to reconsider what evolution is.

   One can imagine applications to biomedicine and robotics, and one can ask whether the term robot is anymore appropriate. This vision raises deep questions in ethics, which is based on the view that life forms are products of long evolution and has been strongly human centered. What are the universal principles of ethics, is the question.

The basic critical question is that the notions of cognition, intelligence, self, multiscale competency, goal, and evolution are not defined at the deeper, presumably quantum physical level. Quantum physics as we now understand it, does not of course allow the formulation of these notions. The same applies to the notions of memory, and self, goal or intention. These notions would require a theory of conscious experience telling what distinguishes living systems from dead systems (if such even exist).

## 2.3 The dream

The dream of Levin [I10, I5] is to understand, recognize, create, and relate to truly diverse intelligences regardless of composition or origin story. Besides understanding of familiar creatures one would understand colonial organisms and swarms, even say something universal about exobiological agents. This would make possible synthetic biology, bio-inspired AI.

Communication with cell groups allows rewriting of the morphogenetic goals. Rewriting would be like activating one particular program module in the hierarchy of program modules. This module would call lower levels modules and in this way recruit the agents at the lower levels of the scaling hierarchy. No knowledge of the details of the process at lower levels would be required. This approach is a diametric opposite to the usual approach based on gene level manipulations.

One can even dream of the emergence of an anatomical compiler, which assigns to a plan of an organism, generated using AI utilizing the available empirical data, a new organism with desired functions. This dream is of course very far from reality. Levin mentions as an example the chimeric embryo formed from azoloti larva and frog larva. The existing models cannot predict what the outcome of the morphogenesis in this case could be.

Regenerative medicine would provide obvious applications for this kind of compiler. Consider only birth defects, degenerative diseases, aging, and cancer. Reprogramming a multicellular level could allow to normalize tumors, repair birth defects, induce regeneration of limbs, etc... Levin mentions also the development of electroceutical drugs based on chemical manipulations of cell membranes. What ions? What ion channels? These would be the basic questions?

Aso other than biochemical tools for the programming of the morphic goal might be possible but this would require a deeper understanding of how the goal identified as a memory is represented. Here quantum biology could come to rescue. One should understand how the goal as memory is defined at quantum level and how the manipulation of the voltages assigned to ion channels affect the goal.

One can imagine applications to computer science, say bio-computers for which search corresponds to finding a goal in the morphospace. Whether this can be realized using ordinary computers or even quantum computers relying on the standard quantum theory, is of course far from obvious.

The goal directed behavior could involve the feedback loop involving sensory perceptions about the state of the organism, which are compared with the goal, and generate feedback as a control signal.

One can also imagine a neuro-inspired view of sensory perception as a pattern recognition and completion in which the morphogenetic goal is represented by standardized mental images representing the possible outcomes of pattern completion. One could also consider the bio-inspired analogue of machine learning.

# 3 TGD view of morphogenesis

The TGD inspired view of life and consciousness leads to a view of morphogenesis discussed in detail in [L18] (2022). The discoveries of Levin's group described in [I7, I8, I15] have been discussed in [L1] (2014).

## 3.1 A possible TGD based view of morphogenesis

The basic notions relevant to the TGD description of morphogenesis.

1. The notions of magnetic and electric bodies (MBs and EBs). Magnetic flux tubes and possibly also sheets form a network connecting cell membranes and higher level membrane like structures. They correspond to EBs formed by light-like outer boundaries of 3-D surfaces representing the bodies of the network.

2. The phases of ordinary matter with effective Planck constant $h_{eff} = nh_0$, tentatively identified as dark matter, play a key role in the TGD inspired quantum biology. These phases can reside at MB and EB. In the models considered hitherto MB is in a key role but it is clear that EB has an important role.

3. The notion of genetic code is generalized. One can speak of dark code with codons realized in terms of dark proton - and dark photon triplets. In the number theoretic vision dark genes are realized as 3N-protons and photons. The so-called icosa tetrahedral tessellations of hyperbolic 3-space $H^3$ define a candidate for a universal realization of the genetic code. The genetic code could be realized at the level of cell membranes in terms of ion channels. One representation for the codons as 6-bit sequences could be as graded membrane potentials. The 2-D pattern of codons would define a set of 2-D genes. Electrical manipulations affect these genes and they become dynamical. This could also define what might be called "morpho-genes".

4. The electric programming of cell groups by electrical manipulation could affect the 2-D genetic codons, which would define the morphogenetic program. This would be possible at the early embryo state during which the system would be quantum critical. The fixing of membrane potentials of ion channels and pumps could fix the frequency of dark Josephson radiation from cell membranes to MB for them and select parts of MB for which cyclotron frequency is same as for the ion channel. This would map the electric pattern of the cell membrane to MB. After this period the situation would stabilize.

5. Zero energy ontology (ZEO) and holography might play a key role. The basic problem is to understand how a goal is realized as a memory. In ZEO the initial state as a superposition of 3-surfaces at the passive boundary of CD would remain invariant during the evolution of the zero energy state. It would naturally define the counterpart of memory and dictate to almost deterministically the evolution of self by "small" state function reductions (SSFRs). The memory would correspond to the part of self which is not changed during the evolution by SSFRs.

   The comparison of the zero energy state defining self would in the simplest model be based on communications to the passive (past) boundary of self with negative energy signals with reversed arrow of time. The feedback would be a positive energy signal back to the future. This process essentially pattern recognition and completion and would gradually lead to the goal. This picture is completely general and morphogenesis would have only one particular application. One can consider more complex models in which the information about the goal at the MB is preserved and sensory communication could be also in standard time direction

whereas the feedback would be in the opposite time direction. "Big" SFRs (BSFRs) would be involved in both cases.

Pairs of BSFRs involving temporary change of the arrow of time could be involved with large error corrections. Note that the sensory communications to the geometric past and the feedback can be seen as a pair of BSFRs at a lower level of hierarchy.

## 3.2 How the membrane potentials and gap junction connections could define morphogenetic program?

The behavior of the planaria is goal directed. There are reasons to assume that this is quite generally true.

### 3.2.1 Facts

1. The membrane potentials and gap junction connection network during the early embryonic stage code for the goal of the organism in morpho-space.

2. After this period, various perturbations, even very dramatic such as mixing of the parts of the embryo, do not prevent achieving the goal and the system is able to correct its errors. There are several ways to achieve the goal: this is interpreted as intelligent behavior.

3. If planaria is cut in pieces, the pieces grow to full individuals so that the memory of the goal is represented in such a way that the splitting does not affect it.

4. The modifications of the membrane potential of a full grown planaria and gap junction network do not affect the goal. One can say that the system goal corresponds to a stable memory of what point of the morpho-space the system should reach.

5. If membrane potential is manipulated and the planaria is cut after the modification, the resulting planaria have a new goal coded by the new pattern of membrane potentials and gap junction network. For instance, the modification can give rise to 2-headed planaria. If one assumes that the development corresponds to an analog of a computer program, one can say that the modifications lead to new morphology only if the planaria is split.

How could one realize this picture in the TGD framework? In accordance with earlier vision, it is natural to assume that MB, or actually a hierarchy of MBs, defines a slaving hierarchy with levels labelled by the values of $h_{eff}$ defining scale hierarchy assignable to hierarchy of causal diamonds (CDs), which are analogs of cognitive light-cones of Levin.

Especially important levels of the hierarchy are labelled by gravitational Planck constant $\hbar_{gr} = GMm/v_0$ originally introduced originally by Nottale [E1]. Here $M$ corresponds to either Earth mass or solar mass and $m$ corresponds to particle mass. The large values of $\hbar_{gr}$ make possible gravitational quantum coherence in long length scales, even Earth scale. The gravitational Compton length $\Lambda_{gr} = BM/v_0$ does not depend on the value of the particle mass $m$ and the cyclotron frequencies of charge with mass $m$ does not depend on $m$: this conforms with Equivalence Principle. This view leads to a view about the role of quantum gravitation in biology [L14, L13, L15].

### 3.2.2 Questions related to the electric coding of the goal

There are several questions to be addressed.

1. Why electric modifications have effect only if they are done during the early embryonic state?

   The possible explanation is that the MB during the early embryonic period is quantum critical and therefore highly sensitive to perturbations of the biological body represented as modifications of gap junction network and membrane potentials. During this stage the classical pattern of membrane potentials correlates strongly with the state of the MB, which defines the goal as memory. Quantum criticality is later lost and further modifications do not affect the goal anymore.

2. How the organ/organism remembers the goal and how the memory can be stable? Here ZEO provides a possible explanation. Zero energy states are pairs of ordinary 3-D states at boundaries of causal diamond CD and represented by superpositions of space-time surface. Holography, which is forced in TGD by the general coordinate invariance, forces almost deterministic correlation between the 3-D states at the opposite boundaries of CD.

   The sequence of SSFRs preserves the state at the passive boundary of CD and passive boundary but affects the active boundary and the states at it and the temporal distance (geometric time) between boundaries of CD increases: this correlates the flow of subjective time as SSFRs with the increase of the geometric time. The sequence of SSFRs defines the notion of self as a generalization of the Zeno effect. The state which is unchanged in Zeno effect is replaced with the memory about the goal.

   By almost deterministic holography, the state at the passive boundary defines the goal of the system towards which it evolves.

## 3.3 How the potential gradient is generated?

The generation of potential gradients is essential in morphogenesis. Potential gradients play a key role also in the brain functions and the direction of the gradient correlates with the state of consciousness. Potential gradients accompany DNA and microtubules. Hyperpolarization occurring during sleep corresponds to a reduction of the level of consciousness. On the other hand, the direction of a long scale electric field determines whether the brain is conscious or not. Therefore the polarization at the level of neuronal membranes correlates with the direction and strength of the electric field. Why this should be the case, is actually far from obvious, and TGD suggests that new physics, involving quantum gravitation, is involved.

From the videos, I concluded that the potential gradient is generated by manipulating the membrane potentials and that the change of the membrane potential of a given cell is constant and is the same at the two sides of the cell membrane defined by direction of potential gradient. I failed to understand how the variation of membrane potentials in this way can generate a potential gradient along part of the body. The manipulation of membrane potentials of cells such that membrane potential is constant for the entire cell membrane does not generate potential gradient.

Potential gradient means that cells are in an electric field for which potential increases in a given direction and is approximately constant inside a given cell. The simplest expectation is that the membrane potential is modified by the same constant amount for the entire cell.

The membrane potentials should be modified in such a way that the membrane potential is different at different sides of the membrane in the direction of the voltage gradient? Intuitively it is implausible that one could achieve a different effect on the opposite sides of a membrane by using the biochemical methods considered for which cell groups are targets and a single ion channel is selected.

Typically the second end of a structure carrying a longitudinal electric field is negatively charged and the second end is positively charged. How is this polarization generated? It seems impossible to generate it by manipulation of the membrane potentials since the change of potential over over distance defined by the cell is not affected at all unless the charge densities at the cell exteriors are rearranged to generate the gradient.

Does the generation of the potential gradient have anything to do with the manipulation of membrane potentials or is the mechanism indirect? It seems that in the case of the brain this is the case.

In the case of axonal microtubules, I have considered a new physics based mechanism based on quantum gravitation in the TGD sense. The mechanism would also generate a change of polarization in the axonal membrane since the effective microtubular charge in the interior of the axon would change.

1. The proposal is that very long "gravitational" hydrogen bonds with length even of order of Earth scale are possible due to the large value of gravitational Planck constant $\hbar_{gr}$. Ions would be transferred from the microtubule to these long hydrogen bonds and go outside the axon-microtubule system so that the effective charge of the microtubule would change

and the transverse electric field created in this way affects the membrane potential. This could give rise to a propagating depolarization giving rise to hyperpolarization.

2. In this way it is also possible to create a longitudinal electric field in, say, the head-tail direction of the organism. This mechanism would be at work also in the case of the brain and relate to the DC currents of Becker [J1]. If the modification of membrane potentials generates a voltage gradient, the manipulation of the membrane potential must induce an effective charging of the cell interior. The number of ions transformed to long hydrogen bonds depends on the value of the membrane potential and that the effective charge depends on the value of the membrane potential being for instance proportional to it.

   This could allow the MB to control the polarization based on the modification of membrane potentials. Actually MB, would keep it constant at the morphogenetic level. In the case of the brain the direction could be changed when the organism falls asleep (BSFR).

3. What the analogue for the choice of a subroutine in the manipulation of embryo or split planarian could mean in TGD? Ionic channels define Josephson junctions and for large values of $h_{eff}$ Josephson frequencies can be even in ELF scale. These frequencies correspond by resonance condition to cyclotron frequencies of dark ions at MB. The resonance condition selects a part of MB to which communication of sensory data is possible and which can control the organism by resonance mechanism. The frequency modulated signal is transformed to a pulse pattern and this pulse sequence could define an analog of nerve pulse pattern [L14]. The empirical findings [I14, **?**, I13, I1] and the TGD view of the role of quantum gravitation lead to identification of new kinds of pulses with the voltage scale in mV scale.

   The goal of the organ is characterized by an electric field pattern, which in turn is dictated by the membrane potentials assignable to channels, pumps and gap junctions. How could the electric field pattern achieve this? The cells along the linear structure send Josephson signals to different parts of MB. Flux tubes whose thickness and therefore B varies?

   Part of the organism corresponds to MB. The magnetic field strength at MB corresponds to the value of voltage at the cell membrane to guarantee resonance in communications. Voltages define a map of an organism at MB. This map is realized only at quantum criticality when the organism is very young and its MB is highly sensitive to the pattern of electric voltages..

## 3.4 How the state of the MB can serve as a template for evolution?

The model for the generation of sensory perceptions, regarded as states of subsystems defining selves, generalizes as such to the development of morphology. The MB contains the representations of possible mental images in sensory perception.

1. In sensory perception, the MB carries a representation of standardized mental images. The sensory input to the MB generates a virtual sensory input to sensory organs, which is determined by the difference between the actual sensory input and desired one. This difference is minimized and the process leads to the standardized mental image nearest to the original sensory input.

   The process continues until the difference is small enough. The signalling from the MB is based on dark photon signals so that the process is roughly million times faster than ordinary nerve pulse communications so that standardized mental images emerge rather rapidly.

2. In the case of morphogenesis, the morphogenetic goal replaces standardized mental images so that the situation is much simpler. The SSFRs define sensory input to the MB and virtual sensory input is replaced with an analog of a motor action, which tends to drive the system towards the goal in the morphospace. There are good reasons to propose that motor actions quite generally correspond to pairs of BSFRs (as analog of death or sleep) changing the arrow of time temporarily and also having interpretation as quantum tunneling events.

   The dissipation with the reversed arrow of time looks like self-organization with respect to the original arrow of time and leads to the final state as an analog of self-organization pattern.

After the second BSFR the system starts to evolve in the original arrow of time. This pair of BSFRs is analogous to sleep, which is known to have a healing effect.

This mechanism would be used in all biologically relevant scales [L23] and would be a basic mechanism of homeostasis making it possible for a critical system to stay near criticality by changing the arrow of time repeatedly. This mechanism saves from the basic problem of robotics: robots tend to fall down since the vertical position is unstable. Note that also the dissipation in standard helps to achieve the final state as a self-organization pattern but is not enough if the system is critical as living systems are.

Morphogenesis would be like carving a statue. MB is the sculptor and starting from a rough sketch and proceeding to shorter scales. Now this process from long to short scales would process downwards in the hierarchy of MBs.

3. If the passive boundary of CD codes for the goal, the sensory input to it should correspond to signals travelling with a reversed arrow of time. Their generation requires BSFR of the system generating them and a pair of BSFRs would define the signal to the MB at the boundary and the response. Is the same mechanism involved with sensory perception?.

### 3.4.1 What happens in the splitting of the planaria?

One can say that in the splitting of planaria replication of planaria takes place. What does this mean in ZEO? Does it correspond to BSFR, SSFR or something different. Or are two new CDs identifiable as perceptive fields of new organisms created.

1. A natural guess is that MBs and EBs replicate. One of the basic questions in ZEO is whether new CDs can emerge. Since the zero energy states have indeed zero energy at the limit of infinitely large CD, nothing prevents their creation in SFRs. This is prevented by the conservation laws in the standard ontology but not in ZEO. The creation of a CD would correspond to a quantum jump which cannot be regarded as either BSFR or SSFR.

   It however seems obvious that standard ontology is a good approximation due to the formation of CD networks in which the CDs are connected by particle lines to form an analog of the Feynman diagram with CDs representing vertices. There the CDs of split planaria would be connected to the CD of the non-split planaria by "particle lines" .However, In principle the generation of CDs from vacuum is possible without a violation of the conservation laws.

2. The simplest model explaining the findings about the regeneration of planaria from split planaria assumes that each split planaria is accompanied by its own CD and its passive boundary provides the memory determining by holography the growth of planaria as an analog of almost deterministic computer program (quantum superposition of them). The non-split planaria of the geometric past and its CD could still continue to exist and make BSFRs and evolve. This would happen even in astrophysical scales and explain stars older than the Universe and the galaxies older than the Universe detected by James Webb telescope [L16].

## 3.5 Some questions

The findings of Levin et al raise interesting questions in the TGD framework.

1. Chinese medicine talks of acupuncture points and meridians. Could these notions be reduced to the hypothesis that ordinary cells form networks analogous to CNS such that communications take place by the analogs of nerve pulses (miniature potentials) in the scale mV scale for which empirical evidence indeed exists [I14, I12, I13, I1] and is discussed from the TGD viewpoint in [L14]. Could the disorders at this level correspond to the loss of quantum coherence at the level of MBs and EBs caused by the reduction of the value of $h_{eff}$ naturally caused by the failure of the metabolic energy feed needed to preserve the distribution of the values of $h_{eff}$. This would lower the "IQ" of MB and the control would fail. Could the splitting of the gap junctions be due to the same reason?

   This would suggest that the healing of disorders could reduce to the control of communications between EBs and MBs and basically to the control of Josephson frequencies (membrane

potentials) and cyclotron frequencies (magnetic field strengths coded by the thickness of the monopole flux tube). Besides chemical tools other tools can be imagined. For instance, irradiation at desired frequencies might be such a tool avoiding the side effects of the chemical tools [L5].

2. The vision of ZEO has developed slowly and the question whether BSFR and SSFR are the only quantum jumps or whether new CDs can be created from vacuum. The model for the splitting of planaria suggests an affirmative answer to this question.

3. A second open question has been whether the passive boundary of CD carries conscious information. The holography of consciousness suggests that the conscious experience at a given level of the self hierarchy remains constant between two subsequent SSFRs. The quantum state at the passive boundary is unaffected in SSFRs so that one can argue that there is no conscious experience giving information of the passive boundary. Could "silent wisdom", determining the goal of the self by holography, characterize the contribution of the passive boundary. Could the state of the passive boundary define "Self" or "soul" as a conscious experience, which tends to be masked by the contributions of the active boundary of CD. This "Self" would be changed in BSFRs.

# 4 About the recent findings of Michael Levin's group

I watched a video discussing two articles just published in Nature (thanks to Marko Manninen for the links). Besides Michael Levin present was Gizem Gumuskaya from the team behind the first article [I3] "Motile Living Biobots Self-Construct from Adult Human Somatic Progenitor Seed Cells". Also Angela Tung from the team behind the second article [I4] "Embryos assist morphogenesis of others through calcium and ATP signaling mechanisms in collective teratogen resistance" participated in the discussion.

It seems that the findings of Levin's group [I7, I8, I15] are really revolutionizing biology. The Darwinian vision of life as a struggle for existence is being replaced by life as survival based on cooperation, where conscious collective intelligence plays a key role. The findings suggest that life forms can be artificially created for various purposes: the applications in medicine can only be guessed at.

I have written a couple of articles [L1, L6, L22] about the observations of Levin's team. These ideas are emerging outside of biology as well: I have considered Gershing's vision of self-building machines from a TGD perspective in the article [L21].

## 4.1 A summary of the findings

A brief summary of the approach and findings of Levin's team [I7, I8, I15] is in order.

### 4.1.1 Epigenesis as means to produce new phenotypes

Instead of genetic engineering, epigenesis would serve as means to produce new phenotypes.

1. Epigenesis can produce completely different outcomes even though the genes are the same: genetic determinism must be given up. Electric fields of the cell membranes in the embryonic stage control epigenesis, but in the adult phase they no longer have an effect. Different phenotypes can be produced in a controlled manner. How epigenesis is realized under the control of electric fields is a mystery.

2. In the approach of Levin's team, there is no need to construct new genomes as in genetic engineering: the same end result, the phenotype, can be achieved with several genomes. Genetic determinism, i.e. the idea that the whole organism is encoded in genes, would be simply wrong. The protein-coding parts of the genes determine the protein level, but the phenotype would be determined by morphogenesis, which would be based on epigenesis.

   A fascinating question is how independent the phenotype actually is on the genome. This kind of independence would be analogous to the substrate independence of AI based consciousness. In TGD this would conform with the idea that the magnetic body (MB) is the boss and

controls the biological body so that the genetic code would be basically a code used by communication and control signals.

3. Epigenesis means that the same basic genome can code for a wide variety of mRNA molecules, which in turn code for proteins: even an mRNA chain does not determine proteins unambiguously, but can be split into parts (slicing), some of which determine a protein. This makes cell differentiation possible, only a small fraction of the genes is expressed, just like only a small part of the modules of a word processing program are in active use.

   The realization of epigenesis relies on chemical modifications of DNA, such as DNA methylation and histone modification, which prevent normal gene transcription locally. Epigenetic expression can vary even on a time scale of hours. On the other hand, epigenetic modifications can be passed on to subsequent generations. What controls epigenesis is not understood. It is not even clear what epigenesis should include: should one just say that epigenetic is all that is not genetic. The notion of morphogenetic code emerges naturally.

### 4.1.2 Membrane potential as a new control level during embryonic stage

1. Already the earlier observations of Levin's team demonstrated that there is a completely new level of control that has been ignored before: the electric fields associated with the cell membrane, which are central to neuroscience but ignored in biology. Only the embryonic stage is sensitive to the effects of the electric fields so that these electric fields can control epigenesis only during this stage. The vision is that there is a multi-level control hierarchy above the genes that could extend even to the population level.

   For instance, in the case of frogs it is possible to induce dramatic modifications of the phenotype such as several heads or no head at all. These modifications are stable and inherited by the next generations.

2. This inspires the idea of creating life forms, biobots, but without applying genetic engineering. Only epigenesis is utilized and has been controlled by manipulating the electric fields of the cell membrane in different ways, for example chemically or using external electric and magnetic fields at the scale of the embryo.

### 4.1.3 From frog embryos to human cells and populations of embryos

Earlier simple life forms such as frog embryos were studied, but now human cells have been the target and the earlier observations are made also now.

1. In the past, xenobots were studied as artificial life forms built from frog cells. For example, cells taken from epithelial tissue can be used. The important thing is that the system is sensitive to the control of the electric field of the cell membrane only in the embryonic stage and the genetic expression stabilizes after that.

2. Now anthrobots [I3] have been studied as artificial life forms formed from human cells. The spheroid shape group of cells generated under normal conditions is transformed by external stimuli so that the usually inward-directed cilia point outward and the structure can move with their help. Embryo is turned inside-out.

3. The population formed by the embryos has also been studied [I4] and unexpected collective effects have been observed. The collective survives a perturbation better than a mere individual. The vision of vulgar Darwinism about life as a struggle for existence (to which also our materialistic view of society relies on) is simply wrong.

## 4.2 TGD view of the findings

Consider now a summary of what has been observed from the TGD perspective.

### 4.2.1 Structure determines function

It seems that at the level of the organism, the 3-D structure determines the function and that these functions are a discrete set in the studied situations. This is highly non-trivial but in line with the TGD vision, which differs from the standard physics in the sense that holography is realized at the space-time level.

3-D surfaces in $H = M^4 \times CP_2$ identified as a generalization of point-like particles of quantum field theories is the starting point of TGD. The 4-D spacetime surface is determined from the 3-D surface providing holographic data and is therefore analogous to the Bohr orbit. The almost deterministic Bohr orbit is analogous to the notion of function of biology, a genetic program determined the structure having 3-D holographic data as a counterpart. Quantum states are superpositions of these Bohr orbit-like space-time surfaces.

What distinguishes TGD from other quantum theories is that there is no path integral so that one avoids the usual divergences and classical physics becomes an exact part of the theory.

In particular, the fact that there seems to be a very small number of different structures and associated functions conforms with holography.

At the quantum level, biological functions are time evolutions that obey statistical determinism. What distinguishes biosystems from deterministic computers is that statistical determinism can be violated because quantum coherence in all scales is possible. Quantum coherence in time scales longer than say the EEG periods implies this violation. This is what makes matter alive. An interesting question is whether this violation can take place also for ordinary computers.

### 4.2.2 Cells behaviour depends on the size of the population

1. A surprising result of [I4] is that cells behave differently depending on the size of the population. Furthermore, cells, embryos, etc... are cooperative social beings helping each other to survive. For example, in a population, a single cell recovers from damages much better than a solitary cell. This happens only if the entire population has experienced the same perturbation. Cells survive better in a larger population and develop differently in them.

2. This strongly suggests the presence of collective consciousness and intelligence, which is much more than what is thought to be, for example, the swarm intelligence of AI systems. The magnetic body (MB) as a conscious entity could provide the TGD realization of collective intelligence and produce a hierarchy of levels of consciousness. The bigger the population, the larger the value $h_{eff}$ as a measure of algebraic complexity and quantum coherence scale also at the level of the individual: this would explain why the increase in population size makes individuals smarter too.

3. When a single cell of the population is damaged, it generates a $Ca^{++}$ wave that spreads to the environment and induces ATP production and $Ca^{++}$ secretion. This involves the transfer of information, which makes it possible for the population to react as a coherent entity, a kind of life form. If the $Ca^{++}$ wave or the generation of ATP is blocked, the embryos behave as if they were alone.

   Communication need not involve mere chemical signals, as the standard biology would predict. It is not understood how the mere presence of other individuals helps in the healing process.

4. What could be this unknown means of communication? This brings to mind the observations of Blackman and other pioneers: ELF radiation at the cyclotron frequency of $Ca^{++}$ in the case of mammals affected both behavior and brain physiology. In the TGD framework, the generation of a $Ca^{++}$ wave could correspond to the communication induced with the help of $Ca^{++}$ ions to a certain layer of the system's magnetic body. Communication would take place at the cyclotron frequency and its multiples, which in Blackman's experiments was 15 Hz and would indicate the presence of an endogenous magnetic field of .2 Gauss, which is 2/5 of the nominal value of the Earth's magnetic field.

   $Ca^{++}$ waves could act like neurotransmitters are believed to do, that is by activating communication lines from cells to the MB. The embryos would become a coherent unit through these connections. The MB would control the entire system. Quantum entanglement in

the scale of MB would be present making the population a coherent unit: mere classical communications are not enough.

5. A nerve impulse would do the same between neurotransmitters. Here one should think critically about the previous TGD view of the role of nerve impulses. According to the TGD view of brain [L2], nerve pulses do not correspond to fundamental communications. Rather, neurotransmitters would simply connect the magnetic flux tubes associated with pre- and postsynaptic neurons to form one long channel along which dark photons with large $h_{eff}$ would propagate from the sensory organs to the cortex and from cortex to the MB.

   A more general alternative would be that dark photons signals to the hierarchy of layers of the MB of the brain take place also from the activated neurons along the neural pathway and not only from the cortical neurons. The activated neurons, the neuronal pathway, would have a quantum coherent and quantum entangled entity at the level of MB and define an association chain at the level of conscious experience. Neuronal synchrony would relate closely to this quantum coherence.

### 4.2.3 Morphogenetic code

The proposed communications should involve a morphogenetic code, which is not understood.

1. TGD inspires the idea that the genetic code as a universal code defines also the morphogenetic code [L6, L18]. Dark codons of DNA, RNA,.. and their counterparts would be realized as dark proton triplets in various scales. Dark genes with N codons would correspond to 3N dark protons. Communications would rely on dark 3N-photons (N would correspond to the number of codons of gene) as analogs of bound states of 3N dark photons would realize the genetic code in the sense that that they would induce 3N-resonant transitions between dark genes as dark 3N-protons.

2. Also the communications between dark and ordinary information molecules would rely on the resonance mechanism. The idea that dark genes are mere copies of ordinary genes does not look attractive. Actually, dark DNA, RNA, etc could be almost independent of their chemical variants and participate in quantum information processing not directly visible at the level of ordinary biomatter. Only in the communications with ordinary gene or its part, dark information molecules could transform to a state corresponding to the ordinary information molecule or its part.

3. The realization of the genetic code could be universal and could correspond to the so-called icosa tetrahedral tessellation of the hyperbolic 3-space and it would appear in all scales, not only in biology [L20].

### 4.2.4 Hierachy of collective intelligences

Levin proposes that collective intelligence is present in several scales. TGD predicts the existence of several scale hierarchies based on a new view of spacetime and a number-theoretic vision of TGD as dual to geometric vision.

I have built a model for the birth of language [K3] based on the observation that the appearance of a few crucial genes was crucial for the emergence of language. The proposal is that this meant the appearance of a layer of MB with a considerably larger $h_{eff}$. A collective level of consciousness on a much larger scale was born. Language would make possible the communication between individuals and promote the birth of these larger collectively conscious structures. Language in human society would have a role similar to that of $Ca^{++}$ waves in the collective behavior of embryos [I4].

Somewhat surprisingly, Levin does not speak at all about the possible role of quantum theory in biology. I think it would be important to build a bridge from the observations of Levin's group to the models of quantum biology. The team's findings force us to take quantum coherence at long scales seriously.

Typically, theories of consciousness do not have much to say about this aspect. One reason, of course, is that standard quantum theory doesn't have much to say.

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