Edited Preamble for Mr. Kukuruznyak's submission to EVO2.0 - *The Flow of Information through Animate Matter and the Origin of Life*

What this submission is about

This submission was written not by a biologist, but by a physicist. It gives a fairly precise definition of life as a physical phenomenon: a living organism is a particularly arranged condensed matter body undergoing the process of self-sustaining collective chemical condensation.

This means the following: from a physical perspective, chemical reactions are the processes in which electrons fall to the nuclei, forming energetically favorable molecular orbitals known as chemical bonds. Biological life involves the same process. Only, in chemistry, matter is broken up into separate molecules. In contrast, biological matter is not divided; all the transformations take place inside of a single connected condensed matter body. For this reason, all the transformations (irreversible falling events) affect each other, communicate, and work out a collective behavior. They do so by reconstructing, restructuring, and rearranging their condensed matter body. Where do they get the power from? The falling electrons convert energy into mechanical work and information under the same laws under which falling water converts energy into mechanical energy. As a result, the living body reconstructs itself, it transfers chemical precursors across its own body, and between the body and the outside world; this causes new irreversible condensation events. Thus, the whole process is self-sustaining. The function of the living body is controlled by its structure.

This submission states that biological (cellular) forms of life are only a small particular case of the described physical phenomenon. This phenomenon is very common in nature. There are non-cellular and non-biological forms of animate matter.

This submission describes how non-biological living matter can be produced in laboratory settings (examples are given). Everyone can repeat these experiments and demonstrate the emergence of (non-biological) life, and even observe the evolution of simple forms of life into more complex forms. Regardless of the fact that these forms are much simpler than biological cells, they generate complex adaptive behaviors based on the same principles that guide real biological organisms.

In this submission, I state that I plan to manufacture artificial animate matter on an industrial scale, and that I intend to fabricate artificial brains for living-like robots from these materials. This is not a computer simulation of neural networks. These are real material objects that solve problems and make decisions using biological principles. These new "computing machines" are much more productive as they perform computations at the atomic scale, in a transforming condensed matter body. The quantity and the speed of these "logical elements" are colossal. Additionally, they have an immense connectivity (they all work in parallel).

The production of artificial living forms as commercial products is a global race and a global challenge. It requires vast resources and a significant amount of time. It will cost billions of dollars and the effort of thousands of researchers. Its success will have implications for deep questions, including: what is our place in the universe? I intend to demonstrate my simplest prototypes using the cheapest materials and equipment. For this reason, I have submitted this proposal to the Evolution 2.0 Prize, wishing to protect my intellectual rights before I sell the company and turn it into profit.

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1. The Evolution 2.0 Challenge (the "Challenge") is sponsored by Natural Code LLC, a Nevada limited liability company, also sometimes referred to in these Challenge Guidelines as "Sponsor." Each entrant to this Challenge who submits a solution to the Challenge is referred to in these Guidelines as an "Innovator."	
2. Is your solution a purely chemical process that will generate, transmit and receive a simple code — a process by which chemicals self-organize into a code without benefit of designer?	NO The solution is NOT purely chemical.
3. To be clear, is your solution a process where some chemicals, at some particular concentration of compounds, at the right temperature and pressure, etc. generate, transmit and receive a simple code, without any intelligent being or other life-form creating, transmitting or receiving the code?	YES However, the most elementary senders and receivers of information are NOT chemicals.
4. Is your solution a formula or transformation process that turns matter into information—directly, with no intelligent being or other life-form making it happen?	YES
5. Is your coded communication system digital, not analog?	Neither digital nor analog. Communication signals are not exactly signals: they carry mass, energy and information.
6. Does your solution have the three integral components of communication, i.e., encoder, code, and decoder, functioning together?	YES
7. Does your solution contain a message passed between the encoder	NO

and decoder components that is in a sequence of symbols forming characters of a finite alphabet?	The message is a material body.
8. Does your solution contain encoding and decoding tables filled out with their values arising from the submitted system or process?	NO The same signal might elicit different reactions in different situations. The outcome will depend on the current states of all senders and receivers of information.
9. For your solution, does a procedure exist for determining whether input correctly corresponds to output?	YES
10. Is the actual system that you are submitting for demonstration of the solution to this Challenge preprogrammed with any form of code? Any system found to have preprogrammed code in it in any form will be disqualified from the competition.	NO
11. Is the system that you are submitting for demonstration of the solution to this Challenge a direct derivative of DNA or produced by any living organism, including viruses and similar entities? Phenomena such as bee waggles, dog barks, RNA strands derived from cells, mating calls of birds, etc. are not acceptable elements of a winning solution to this Challenge.	NO
12. Is the origin of the system that you are submitting for solution to this Challenge documented to show that its process of origin can be observe in nature and/or duplicated in a real-world laboratory according to the scientific method?	YES

I am the founder and the principal materials scientist at the Moscow Animate Materials Center. I develop animate-like materials suitable for fabrication of synthetic quasi organisms with independent autonomous behaviors. In addition, I develop methods for quantitative description of animate matter.

In my submission, I show that life <u>cannot</u> be adequately described by means of information theory, exclusively. A living organism is <u>not</u> a purely cybernetic system. While performing signal processing, purely cybernetic systems transform information messages into other information messages, and nothing else. Animate mater, on the other hand, converts matter into information. Thanks to this fundamental capacity, living organisms can invent new things. This effect is essential for understanding evolution.

In his attempts to describe living matter, Perry Marshall performs an improper “reduction of variables”. He reduces the complete body of the cell to its “genetic code”. He disregards information stored outside of DNA. This is incorrect. DNA is only a part of the code. The living body as a whole makes the “complete pattern”. Importantly, the living pattern constantly transforms, reconstructs, and modifies itself in orderly ways. Because of this, it can modify DNA during replication.

The Flow of Information through Animate Matter and the Origin of Life

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This article is written for the Evolution 2.0 challenge, in which a group of philanthropists is offering $10 million prize to the first scientist who explains the origin of information recorded in DNA and describes the flow of signals through living organisms.

In this manuscript, I argue that animate organisms undergo collective chemical transformations, which require information communications. However, these communications are not purely chemical. They start at the atomic scale. When active atoms reconstruct their chemical bonds inside transforming molecules, they arrange their local atomic neighborhoods. These transformations interact and combine into collective reconstructions, producing ordered molecular motion. Similarly, animate bodies, which consist of connected and orderly packed molecules, produce larger collective reconstructions. Consequently, animate bodies arrange their own constituents at several length scales. They control the ongoing chemical processes, synthesize special products, and build ordered structures that cannot appear accidentally in inanimate matter.

In this paper, I specify situations in which primitive animate bodies appear naturally. In the language of the prize organizers, I describe the emergence of the simplest "designers" that make simple material records of their actions. Those may further evolve into proper genetic codes. I show the blueprints of the simplest animate organisms and describe the flow of information through these organisms.

I also contend that some non-biological compounds may acquire properties analogous to those of biological animate matter. Their elements undergo similar atomic transformations and convert matter into mechanical work and information. In such materials, these transformations communicate using similar signals. The animate-like materials can be used for fabrication of artificial "designers" capable of building ordered atomic arrangements. In addition, they can be used for fabrication of autonomous robots that take purposeful voluntary actions.

1 Introduction

1.1 The Evolution 2.0 Prize

One of the biggest questions in natural science today is what, exactly, is life, and how it got going.[1] This is illustrated by the Evolution 2.0 prize, in which a group of investors is offering $10 Million USD to the first scientific team that can explain the origin of the genetic code.[2]

The winner of the prize should describe the origin of information and the flow of signals through living matter. In essence, the winner should provide a satisfactory quantitative model of a living organism. The construction of numerical models of living organisms is the ultimate goal of the physics of life.[3] Therefore, the winner should effectively establish this emerging discipline, or make a significant contribution toward this objective.

The sponsors of the prize acknowledge that their interests are not strictly altruistic. They intend to patent the principle of communications in living organisms, to create artificial intelligence devices based on this principle, and to commercialize them in partnership with the winner.

1.2 Animate matter vs. inanimate matter

A living cell may be regarded as an evolving (transforming) condensed matter body in a distinctive animate state. In this non-equilibrium state, matter is transformed into energy and information through particular chemical processes. In the cell, these transformations interact with each other. They adapt to each other, coordinate their efforts, and combine into large collective transformations. The resulting collective transformations involve mechanical movements and topological reconstructions of animate bodies. By means of these collective reconstructions, cells reorder themselves, synthesize special chemical compounds, and build regularized structures.

In addition to new animate matter, cells produce ordered inanimate artifacts. Those remain in the equilibrium state, meaning that they never transform by themselves. Some of these artifacts are used by the cell as templates and information carriers. They encode sequences of precise actions needed for controlled fabrication of complex products. The most popular of such artifacts is DNA.

Perry Marshall — the author of the book Evolution 2.0 and the main organizer of the prize — suggests that all processes in living cells are controlled exclusively by these (inanimate) records.* The inanimate DNA may be regarded as a carrier of a particular information message that has the capacity to rewrite itself. (It does this in cooperation with the animate body of the cell). Additionally, this message can evolve and modify itself during replication, for instance by exchanges with other messages.[4]

*Generally speaking, this assumption is not sufficiently grounded: Living cells do make written notes for themselves; they can execute programs. However, cells also assimilate vast quantities of external information and adapt to their environment. This means that the behavior of the organism is controlled by the whole body of the cell, including its animate (i.e. transforming) structures.

1.3 The code and the code designer

Perry Marshall calls the instructions written in DNA "the code". In the same vein, the animate parts of the cell could be termed "the code designer". In addition to writing and executing, the designer modifies the code. The emergence of life boils down to the emergence of this pair — the code and the code designer. One needs to establish where it came from, and how it has evolved to what it is today.

Perry Marshall wants to check if the code (genetic information) could have emerged — and further replicated — solely by itself, without the animate working body. He clearly states: The challenge is "to discover a purely chemical process that will generate, transmit and receive a simple code — a process by which chemicals self-organize into a code without the benefit of a designer".

The point of view that ignores the ordering acts of the animate body does exist. It assumes that life is a process in which genetic molecules simply catalyze their own replication. Catalytic compounds never take any purposeful actions. They use available random motions of atoms and molecules.

There are numerous complex catalytic molecules that catalyze their own replication. However, it has not been proven that this catalysis has anything to do with life. The thing is, in real cells, DNA never replicates by itself. It is being replicated with the help of special active proteins termed "molecular machines".[5] These molecular machines physically manipulate atoms with great precision.

1.4 Modifications of the challenge

From a physical point of view, no random process can create a meaningful message.[6] At the same time, a non-random process capable of creating meaningful content implies a designer. In our situation, the message is created together with a material information carrier. Therefore, the designer must be able to execute ordering manipulations of matter. From this standpoint, the main condition of the challenge ("a process by which chemicals self-organize into a code without the benefit of a designer") contains a contradiction. In its present form, the problem has no proper solution.

In this paper, I will take the liberty to eliminate the contradictions that are built into the terms of the prize. I will also ask the organizers to change the conditions of the prize. I am doing this for the sole purpose of defining a well-posed physical problem.

First and foremost, I suggest changing the main assignment of the challenge: Instead of looking for an impossible process, I will describe a process by *which animate condensed matter self-organizes into the "code designer".* The "designer" is understood as an arranged condensed matter body that purposefully reorders matter on its own volition.

Throughout the paper, I will concentrate on non-equilibrium animate matter instead of inanimate records created by this matter. In this paper, I will explicitly specify transformation processes that produce biological information. Also, I will explain how different transforming parts establish communications, and how they organize large collective processes. I will contend that the animate state of matter does not require any new interactions or forces. Matter comes alive when its atoms jointly arrange chemical bonds.

1.5 Physical phenomena related to life

In order to explain how animate matter produces new information, which forces are responsible for the evolution of living organisms, and where the first animate bodies came from, one needs to give a clear answer to the fundamental question "what, exactly, is animate matter".

From my point of view, the animate state could be understood if someone identifies non-biological condensed matter phenomena related to biological life. *I contend that biological life has enough natural abiological relatives.*

1.6 Non-biological living-like condensed matter

In order to be related to biological animate matter, non-equilibrium condensed matter must sustain collective transformations of its own elements. Structural elements of condensed matter (atoms and chemical bonds) can transform into something else and produce other elements. Some of the transformation products can move through the body, and affect other elements. Therefore, individual localized transformations may interact. They may also link together, and create extensive collective reconstructions. When these reconstructions induce transformations of new elements on a regular basis, the transforming matter can sustain itself in the transforming state.

The most common example of such transforming matter is the deep interior of a star. Its transforming elements (hydrogen nuclei) fuse into heavier elements. They produce photons, which carry mass, energy, and information. The fusing nuclei interact by means of these photons. In the deep stellar interior, the density of irradiation is so high that a pair of fusing nuclei can emit and absorb many different photons, and interact with many other fusing pairs. Consequently, the transformation of a star can proceed not as a sequence of individual fusion events, but as a single star-wide collective process. In other words, the whole process of stellar transformation can be regarded as a single complex process composed of interconnected and interdependent fusion events that communicate with each other, modify each other, and induce transformations of new (previously inactive) nuclei. This situation is illustrated in Fig. 1a.

1.7 Biological animate matter

In this paper, I will argue that biological animate matter undergoes similar collective transformations. It contains atoms that break, build, or reconstruct their chemical bonds. The reconstructing molecular orbitals convert matter into energy and mechanical motion. Specifically, they generate ordered mechanical relaxations of the condensed matter body. Through these relaxations, the body realizes collective (opposite of individual) reconstructions of the chemical bonds. This process is shown in Fig. 1b.

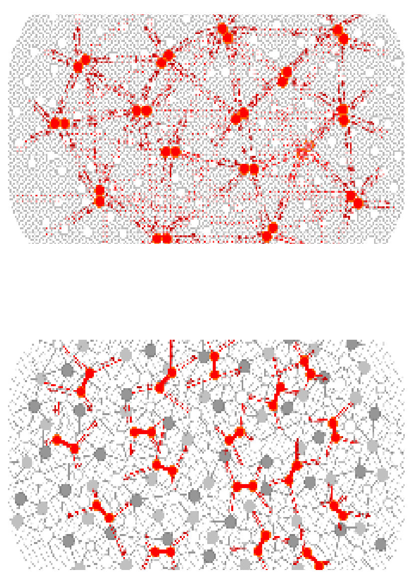

Fig. 1. Communicating transformations in condensed matter: (a) fusing nuclei exchange photons; (b) emerging molecular orbitals interact using collective relaxations of condensed matter.

At mesoscopic length scales, the ordered collective reconstructions transfer chemical precursors and trigger new chemical transformations. Thanks to that, animate bodies sustain themselves in the transforming state.

Animate and inanimate matter differ in composition. Inert inanimate matter consists of unchanging atoms and chemical bonds, and nothing else. In contrast, animate matter contains transforming elements that convert substance into energy and vice versa. In modern terms, these elements are called “active agents” because they produce autonomous actions. In addition to the active agents, animate matter contains mobile elements that carry interactions, energy, and matter. In stars, the mobile elements are the photons. (In this case, irradiation is a component of condensed matter.) In biological materials, the mobile components are the ordered mechanical relaxations and various mobile metabolites. In all cases, the mobile components of condensed matter could be regarded as signals.

1.8 Who I am

Now I have to explain who I am, and why I believe that I can qualify for this challenge.

I am not a biologist. I am a physicist and a materials scientist who studies transforming condensed matter that generates self-sustaining reconstructions.[7] It can be said that I study simpler material counterparts of biological animate matter. I believe that non-biological animate-like matter can be used for manufacturing simple artificial animate beings. These non-biological animate organisms could serve as a convenient experimental and theoretical workbench for modeling and understanding real biological life.

In particular, I explore non-biological material systems that generate reconstructions with strong ordering capacities, especially those that regularize matter at several length scales. Such condensed matter is required for two major purposes. Firstly, it is needed for the production of unique functional materials. Their bodies must control autogenous chemical processes, synthesize specially constructed molecules, and build structures that cannot appear in inanimate matter by means of random events. Secondly, the artificial animate materials should be used for fabrication of autonomous robots.

That being said, I am not a synthetic biologist. I have no intention of building complete self-sufficient artificial organisms capable of surviving and proliferating in given complex environments.

2 The Animate State of Matter

2.1 Basic facts about animate matter

In this article, I will define a form of life as a specially arranged condensed matter body immersed into a certain inanimate habitat, which is a larger condensed matter body. The living body orderly manipulates its own constituents and some parts of its habitat, builds new ordered structures, and incorporates them into its own transforming body. For this purpose, it exchanges material with its habitat.

Along with the mechanical movements and structural reconstructions, the living body implements chemical transformations. The chemical transformations and the mechanical reconstructions mutually cause each other.

Additionally, the chemical/mechanical transformations are organized in specific ways. Living bodies consist of different parts that transform jointly. The transformations communicate, adapt to each other, and work out coordinated collective actions. This implies a particular system of requests and feedback, a certain hierarchy and subordination, and, perhaps, a method of elaborating consensual or compromise-based decisions.

In the next section, I make an additional assumption regarding the nature of living matter. It will significantly differ from the conventional point of view.

2.2 The key attribute of animate matter

Presently, most scientists believe that life emerges at the molecular scale, i.e. that life is an effect of some intermolecular interactions. In this paradigm, biological tissues consist of separate molecular bodies that exchange chemical signals.

In conflict with this point of view, I argue that the living cell is composed of molecular bodies that are held together by means of chemical bonds, through which they create a single “giant macromolecule”. This “giant macromolecule” makes ordered reconstructions; i.e. the cell reshuffles its parts in an orderly fashion.

In this paradigm, life is an effect of intramolecular i.e. interatomic interactions. New information appears at the atomic scale, generated by the transforming chemical bonds. Communications between different transformations take place inside a *single molecule. Self-ordering and self-organization of animate matter originate at the atomic scale.*[III]

2.3 Intermolecular interactions and chemical signals

The assumption that life is an effect of intermolecular (i.e. exclusively chemical) interactions is built into the terms of the Evolution 2.0 prize. The challenge states that the winner must "discover a purely chemical process that will generate, transmit and receive a simple code…"

From the standpoint of the prize organizers, life could have emerged roughly as follows. A precursor of a living body would be a regular liquid, in which molecules are detached from each other. Consequently, these molecules occupy random positions, and move chaotically, driven by aimless thermal fluctuations.

This unordered medium would contain chemically active bodies undergoing some internal chemical transformations. These bodies would emit and absorb some signaling molecules that move at random. The absorbed chemical signals would tell the recipients how to act. As a result, the chemically active bodies would modify their actions, orient with respect to each other, form ordered arrangements, and begin performing some kind of a "dance of life". I argue that such interactions would never produce life. Below I explain why.

2.4 A jellyfish in a blender

Contents of a living biological cell do appear very much like a regular liquid. They are composed of the same ingredients as a regular liquid. Take a jellyfish as an example. It contains about 97% water, 2% mineral salts, and about one weight percent of organic compounds.[8] For comparison, regular seawater contains 97% water and 3% mineral salts. However, a jellyfish is not a liquid. Its body could be stretched or flexed or deformed in many other ways. However, all its parts cohere together and keep strict relative positions with respect to each other. The body of the jellyfish is more like a connected and ordered "giant macromolecule".

The jellyfish could be easily turned into a liquid. For this purpose, it should be put in a blender, and chopped into separate molecules. The jellyfish will inevitably die. Instead of a living animal, one would obtain a liquid identical to the "primordial soup".[9] In this liquid, some detached molecular bodies would continue certain internal chemical transformations, and, perhaps, emit and absorb chemical signals. This chemical activity could go on for a while. However, this system will never self-organize into a new animate body. The death caused by the destruction of the animate body is irreversible. If life were an effect of intermolecular interactions, on rare occasions, the destroyed living organisms would self-organize into new living bodies. But this never happens.

2.5 The real dance of life

I assume that — just like the body of the jellyfish — the body of a biological cell is a giant interconnected macromolecule. It is composed of water reinforced with organic compounds. The body of the cell is something like an ordered polymer. Only it contains many different structural components. The surrounding water is also a polymer. Only this polymer is more homogeneous, less ordered, and less robust. It can be mixed much easier.[10]

However, the cell is no ordinary macromolecule. For as long as it is alive, this giant macromolecule — independently, and on its own volition — makes orderly reconstructions. It makes internal rips, separates numerous moving parts from its own body, transfers them into new places, and then reattaches them to its own body by means of new chemical bonds. Then it makes new rips, carries out new material permutations, and so on.

The "loose parts" of a living cell, which at first glance appear as Brownian particles, are not Brownian. Instead of random rips, and aimless chaotic motions, they make ordered movements.

2.6 The consequences of orderly reconstructions

I contend that animate bodies generate ordered reconstructions at all length scales starting from the atomic scale. At the molecular scale, cells manipulate chemical precursors embedded in their own bodies, and synthesize compounds that cannot appear accidentally in inanimate matter. *Animate and inanimate substances synthesize different chemical products.*

The ordering manipulations of matter continue on mesoscopic scales, where cells arrange freshly manufactured molecules, and build structures that cannot appear in inanimate matter haphazardly. *Animate and inanimate bodies build different structures.* (Fig. 2)

Inanimate solids and liquids make random chaotic reconstructions. Consequently, chemical reactions, which occur in inanimate matter, yield simple products. Transformation of inanimate matter is described by regular thermodynamics, chemistry and chemical kinetics. In contrast, animate matter generates and accumulates distinctive ordered structures. Transformation of animate matter should be described by a special branch of condensed matter physics that explicitly treats the ordered reconstructions. That is “the Physics of Life”.

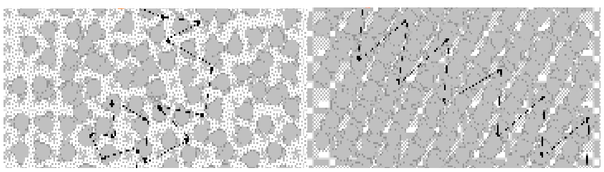

Fig. 2. Inanimate liquid vs. animate matter at the molecular scale. (a) Inanimate matter is composed of unordered molecules. The particles of the liquid make random chaotic movements. (b) Animate condensed matter is composed of oriented molecules held together by means of chemical bonds. The animate body makes ordered reconstructions. Its particles make ordered movements.

There is one important point. In addition to the ordered reconstructions, cellular “giant macromolecules” undergo regular Brownian-type chaotic reconstructions caused by thermal fluctuations. Living organisms constantly repair the inflicted damages. Additionally, cells always contain “completely loose parts”. Those include oxygen, carbon dioxide, various ions, and other small molecules. They diffuse right through the organisms’ bodies. These detached molecules are needed for the normal operation of the organism. However, they do not belong to the organism.

2.7 The cause of ordering reconstructions

I now return to the question what sets the animate cell into orderly motion. In my manuscript entitled “The Physics of Life. Part 1: The Animate Organism as an Active Condensed Matter Body”, I suggested that the purposeful motions are caused by the chemically active atoms that establish, break or reconstruct their chemical bonds.[I]

In fact, all atoms — except noble elements — aim to establish material bonds with other atoms. These chemical bonds must have certain narrowly determined parameters: every atom must have a specific number of bonds of specific lengths, bond angles, etc. For this reason, when a given atom builds a new chemical bond, it moves its partner atoms, placing them in needed positions.

Now imagine that the bond building (termed “condensation”) takes place in a big well-connected three-dimensional molecule. The individual atomic motions will be hindered by the condensed body. (Very often, they are completely prohibited.) The individual atomic permutations will be replaced by the collective reconstructions. Such reconstructions are much slower than any of the single-bond reconstructions as they involve simultaneous movements of many atoms and bonds.

Chemical reactions can take place in liquids composed of detached molecules. In such liquids, active atoms also establish and reconstruct bonds and physically manipulate other atoms. However, these orderly manipulations can only occur within the limits of separate molecules. These motions cannot be transferred onto the neighboring molecules. They will be converted into chaotic molecular motions. Without the interconnected three-dimensional body, there will not be any large collective reconstruction. For this very reason, the blended jellyfish will never reassemble into a new ordered structure.

2.8 The unique capacities of collaborating atoms

The atoms that realize complex collective reconstructions in pre-arranged three-dimensional bodies acquire unique abilities that individual atoms never had. Consider an atom that wants to replace a dissatisfying chemical bond. To do so, it should find itself a new partner, break the existing bond, accomplish an atomic transposition, and build a new chemical bond. It would never achieve this goal on its own. However, it can do all of that in partnership with a large group of cooperating atoms. The reconstructing condensed body will help the atom to break the bad bond, push away the dissatisfying neighbor, select a more satisfying atom, and make a new bond.

By the sequences of the collective reconstructions, a group of cooperating atoms will satisfy the needs of a majority of its members. They will end up in a more energetically favorable configuration, and create a more effectively packed condensate.

Every single atom aims to put its atomic neighborhood in order. Acting together, these atoms will make their common condensed body more ordered. I assume that this particular effect causes self-ordering of living matter.

2.9 The source of biological life

Without due proof excessive for this paper, I will name a pair of atoms that produce a new chemical bond an elementary living subject. It is the elementary animate creature with its own very complex and adaptive behavior. It transforms matter into energy and information and objectifies new information by building new ordered atomic arrangements. It is the simplest designer.

Inanimate condensed matter becomes animate when populated with these elementary animate subjects. In order to come alive, the body must accomplish collaboration between the agents and produce collective transformations. For this purpose, the body must be particularly arranged. *Briefly, biological life is a form of existence of cooperating elementary living subjects.* The elementary living agents adapt to each other and work out coordinated actions by altering the structure of their common condensed matter body.

2.10 Condensation

The fundamental physical force that animates matter originates from the capacity of the atoms to create chemical bonds, link together, and create arranged condensed matter. Biological life is driven by the process of collective chemical condensation.[III]

In the simplest case, the collective condensation involves adding of lacking chemical bonds to an already existing condensed matter body. This happens, for instance, in folding proteins.[11]

A more complicated case of non-random collective condensation takes place in condensed matter bodies that have many unsatisfactory bonds. Such bodies store significant amounts of chemical energy. They generate various mechanical actions by making collective reconstructions.

The growth of a living body also boils down to the organized collective condensation. Growing organisms appropriate new atoms from their habitats producing better-packed condensates in their own bodies.

Making highly ordered inanimate artifacts, such as DNA, is a consequence of the collective chemical condensation.

2.11 Independent wills of animate organisms

It is safe to say that the desire of the atoms to condense produces the wish of the animate body to make a voluntary action. This desire combines from myriads of individual desires of different atoms to improve their chemical bonds.

In a biological organism, mostly carbon, oxygen, and hydrogen improve their chemical bonds. Therefore, it is safe to say that the wills of the organisms mostly arise from the individual atomic wills of these particular elements.

I would like to emphasize that the condensing body has a will to transform, but may lack a particular goal. It could satisfy its desires in a million of different ways, execute millions of different actions and end up in a million of different final configurations. In many of these configurations, it can be more or less equally satisfied.

In addition to the internal desires, the organisms' actions are determined by the internal constrains, set by the intrinsic structures of the organisms. The organisms may also use DNA and other similar guides. Thanks to the genetic codes, they make exact predetermined actions.

In this part of the manuscript, I introduced the animate state of matter. I did not yet explain where the first animate body came from. This will be explained in the last part of the manuscript, where I show the blueprints of the simplest organisms. Now I turn to the main question of this paper. Namely, I describe information communications between different active agents.

3 Information Communications in Living Organisms

In the previous section, I said that condensed matter becomes animate when populated with elementary active agents. These agents are the atomic pairs that build, break or reconstruct chemical bonds. The elementary living agents convert matter into energy, and emit and assimilate mobile elements of condensed matter. These mobile elements carry interactions and may be regarded as information signals.

3.1 Signals in transforming biological matter

The emission and assimilation of signals in transforming condensed matter is an ordinary thing. It occurs in all substances in which elements undergo stimulated transformations. It happens, for instance, in nuclear fuels. In these compounds, the decaying nuclei emit neutrons that cause new nuclear fission events. The neutrons may be regarded as signals. They are produced by the sources (splitting nuclei) and assimilated by the recipients (unstable nuclei).

A similar signaling system exists in condensed matter bodies that reconstruct their chemical bonds. When a pair of atoms forms or breaks a chemical bond, it moves its neighboring atoms. In a big three-dimensional macromolecule, these movements affect other chemical bonds. The “signals” are the mechanical relaxations of the macromolecule.

The nuclear and the intramolecular signals differ in one very important respect. In nuclear reactors, different neutrons move independently from each other. Consequently, nuclear fission proceeds through sequences of simple irreversible events connected by simple causal links. Those are known as chain reactions. In contrast, in biological matter, different signals bind together and mix. As a result, all irreversible events connect, and create a densely interlinked network. Every irreversible transformation has many causes and many consequences. And that is not all.

Animate macromolecules constantly modify their own structure. Correspondingly, they constantly change the communication channels between the sources and the recipients. At any moment, some processes may stop affecting each other; some previously disconnected processed may become connected. The exact mathematical description of such evolving substances is very difficult.

3.2 Collective permutations

In my paper entitled “The Physics of Life. Part 2: The Neural Network as an Active Condensed Matter Body”, I attempted to identify a particular solution of this complex problem.[II] I said that collective reconstructions should resemble localized atomic permutations. The collective reconstruction should proceed roughly as follows. The condensed body spontaneously makes an extended rip in itself, forces out a piece of material from itself, transfers it to a new place, and reattaches it to its body by means of new chemical bonds. The empty space, which was left after the initial rip, is filled with new material, and is also restitched with new chemical bonds. This process is illustrated in Fig. 3.

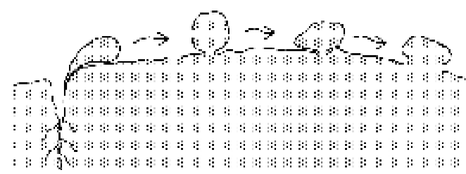

Fig. 3. Autonomous collective reconstruction of the condensing body. The body generates an internal tear, then transfers a piece of itself to a new location.

3.3 Reconstructions in chemically inhomogeneous substances

This section articulates the key idea of this paper. Here I describe collective reconstructions that occur in chemically inhomogeneous matter. In this special case, the transferred pieces carry chemical precursors. Upon reaching their destinations, these pieces cause new chemical reactions and trigger new collective reconstructions. The full reconstruction of the chemically inhomogeneous body will proceed as a cascade of chemically stimulated permutations. This situation is illustrated in Fig. 4.

The collective reconstruction of a chemically inhomogeneous substance will look like directional transfer of certain mobile metabolites. At the molecular length scale, the animate organism will resemble a collection of chemically active molecular bodies — the sources and recipients of various mobile metabolites — that communicate via certain chemical signals. Only, this is not the most elementary length scale of living matter. Thanks to interatomic interactions, the chemical signals do not move randomly. They are involved in a complex regular motion. All the rips and permutations pertaining to the animate state (1) are not accidental, they are willingly generated by the living body; (2) are aimed and directional; (3) are interrelated. All the individual chemical and structural transformations are integral parts of one big orderly transformation of the living body.

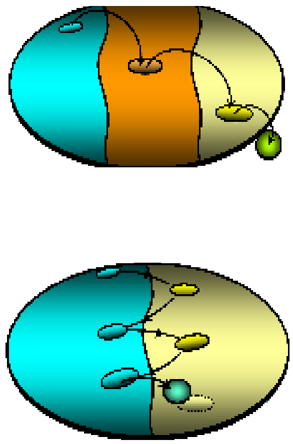

Fig. 4. Collective reconstructions of chemically inhomogeneous animate bodies. (a) propagation and transformation of moving metabolites; (b) back and forth motion and transformation of moving metabolites at the interface between two segments with different chemical composition.

3.4 Multiscale reconstructions

In real biological cells, different small transformations combine into larger collective processes for several times.[12] Every time they do so, they produce a new level of integration. Eventually, they produce a cell-wide autonomous reconstruction known as cyclosis or cytoplasmic streaming.[13,14] This self-sustained mechanical movement is seen through a regular microscope.

Modern biological cells are multiscale systems; they produce multiscale reconstructions. At every length scale, the reconstructions proceed with different speeds. The bigger is the length scale, the slower is the characteristic reconstruction. The fastest processes occur at the atomic scale: it takes approximately 10 nanoseconds to create a new chemical bond.[15] In comparison, it will take approximately 10 microseconds to generate a signal between two neurons.[16]

Evidently, creation of cooperating groups does not stop at the cellular level. It goes on further, producing multicellular organisms. The condensed bodies made of cooperating cells produce even more complex collective reconstructions. Perhaps, the most complex multicellular reconstruction is the operation of the human brain. The brain is an evolving (transforming) condensed matter body composed of living neurons that establish and break material bonds with each other, exchange electrochemical signals, and generate complex coordinated actions.

In my paper entitled "The Physics of Life. Part 2", I suggested that the brain generates collective reconstructions in the same manner as simple animate bodies produce collective moves at the atomic scale.[II] These processes entail the same principle. From this, I described the emergence of the "collective mind", and explained how this collective entity controls the individual neurons.

3.5 The organized information

Biological signals have one characteristic feature. They consist of numerous different components combined into very complex composite messages. Correspondingly, these complex signals cause very complex multi-component events, which involve large networks of elementary irreversible events connected by means of multiple causal links.

Every recipient of biological signal could be called "an observer". The observer assimilates information by performing some complex irreversible actions that involve chemical and structural transformations. The observer sees the outside world not as a set of separate bytes, but as a coherent (connected) picture.

When we perceive the world around us, we recognize the relationships between different events. We can identify different cause-and-effect connections. The smarter is the organism, more elaborate is the picture, the larger is the number of connections between different events it can notice. Recognition of complex patterns is the base of understanding. This particular ability distinguishes us from computers.

3.6 Peculiar characteristics of biological signals

One has to keep in mind a very important fact. The biological signals are not exactly signals. Or rather, they are not only signals. In addition to pure information, they carry energy and matter. In strict physical terms, they are mobile elements of transforming condensed matter. In chemically inhomogeneous matter, they are mobile metabolites.

This should be true for all different signals at all different length scales, including the elementary signals emitted by the transforming chemical bonds. In my papers entitled "The Physics of Life", I imply that one could create a universal theory of animate matter, equally applicable to any length scale, including the atomic scale. In this paradigm, one must assume that the elementary active agents emit information, energy, and matter in the form of some kind of "elementary mobile metabolites". At the first level of integration (molecular scale), these elementary entities link together to form larger mobile metabolites.

3.7 The difference between biological organisms and computers

From a physical point of view, a living organism is an evolving condensed matter body, driven by the active elements that undergo collective transformations. The transforming elements exchange mobile metabolites, which double up as information carriers. As such, a living organism is not a counterpart of a computer. In the strictest sense, it is not a device that executes codes, performing signal processing; and it is not a digital communication system.

The biggest difference between computers and living organisms is that computers never generate new information and never act on their own volition. Living organisms constantly do so. They derive new desires from the digested chemical precursors.

The interactions in animate matter are completely different from computer communications. Biological signals are not orders; they are requests. They never have exact addressees. Any signal could be assimilated by numerous different recipients executing similar (or sometimes even dissimilar) actions. The signals could be easily lost. The recipients are not real recipients. They are observers. Instead of taking in and processing separate signals, they "see the big picture" composed of different interlinked components, and assimilate information selectively. They can ignore parts of the picture. The recipients could combine signals with other signals, add some new information, and relay them to other recipients. The same signal might elicit different reactions in different situations. The outcome will depend on the current abilities and needs of the recipients. Additionally, is will depend on the current states of all the other senders and observers throughout the body as the signal remains connected to many structural elements of the body.

Finally, in addition to making irreversible changes in the recipients, the signals also change the channels of communications. In my paper entitled "The Physics of Life. Part 2", I argued that the characteristic animate-like behavior comes from the interplays between the activities of the agents and the structural modifications of the condensed bodies.[II] For instance, the decision to start an action is made when the animate body breaks multiple internal constraints. This process has much in common with voting, submitting minority groups to a majority, and forming consensus.

To recap briefly, biological signals are NOT used for mechanistic computations. They are meant to request responses from other living subjects. By means of the signals, different animate agents coordinate their actions.

3.8 The request to modify conditions of the challenge

Living organisms create orderly arranged material artifacts. Those could be regarded as permanent records of their earlier actions. Therefore, living organisms may be regarded as certain "designers" that write certain "codes". The animate bodies also read and execute these codes. <u>*This does not mean, however, that the designer itself is a collection of programs executing written instructions.*</u> Similarly, humans can write and read memos, and execute written commands. Nevertheless, it does not follow that a human is a combination of memos and machines executing written programs.

Now I cite Perry Marshall:

> **What You Must Do to Win The Prize**
>
> "You must arrange for a digital communication system to emerge or self-evolve without "cheating." Without explicitly designing the system, your experiment must generate an encoder that sends digital code to a decoder… You have to be able to draw an encoding and decoding table and determine whether or not the data has been transmitted successfully…"

<u>*Above, I wanted to demonstrate that this assignment has no relation to biological life.*</u> Animate matter contains inherent "designers" and "observers" that communicate, form coordinated groups, and produce collective "designers" and observers". However, their communications follow different rules: There is no digital code. There are no preset encoding and decoding tables. There are no separate bits of information.

A strict and comprehensive description of the internal communications in living organisms is well beyond the scope of this paper. Here I simply ask the organizers to modify the terms of the challenge. If they find it possible, I can further elaborate on this issue.

4 The initial stages of life's evolution. Transition from the inanimate state to the animate state of matter

Here I briefly touch upon the origin of DNA. This issue preoccupies the organizers because they tend to reduce life to reproduction of genetic codes, and consider DNA as the first replicating molecule. I argue that DNA is a complex ordered artifact that can only be produced by advanced living organisms that have come a long way in development. I suppose that the first living bodies may have emerged much earlier than DNA, and that they could function without DNA, using some alternative means of propagating structural information.

4.1 The first animate working body

It is generally believed that, in cells, transforming organic molecules perform most actions, whereas water remains relatively inactive. This is indeed the case for modern cells; they manipulate matter mostly with the assistance of protein-based molecular machines.

However, this may not have been the case for primordial proto-cells. Chemical transformations may occur in water, directly. In this situation, water may acquire the capability to carry out basic ordered reconstructions, to manipulate its own constituents, and to synthesize new types of organic molecules. To have such a property, water must be a poorly ordered polymer.

I hypothesize that the earliest animate "working body" was water. *Water may have been the first compound that crossed the boundary between the inanimate and animate realms. It did so when — in addition to totally random reconstructions — it started to produce some non-random reconstructions.*

As a matter of fact, I believe that ocean water still remains at this divide today: in some situations it behaves as a disordered solution, and in other situations it acts as an ordered polymer. The non-random reconstructions occur in water under some special conditions.[17]

4.2 Increasing complexity of the first animate body

Figure 5 illustrates a primordial animate condensed matter body. This poorly ordered polymer is composed of water and some low-molecular-weight precursors. It undergoes collective condensation by producing new organic molecules with increased molecular weights. The primordial animate body accumulates these molecules, becoming more intricately structured. Consequently, it may produce increasingly more complex and more diverse products. Each subsequent condensation event occurs in a better-ordered configuration. Therefore, the orderly condensing body may self-organize and increase its regularity at a growing pace. (This will only work up to a certain limit. The orderly condensing body may run out of some needed chemical precursors. The excessive accumulation of organic condensates may eventually introduce internal conflicts and cause chaos.)

The increase in structural complexity comes from the atoms, which have the capacity to execute ordering atomic reconstructions. During the collective condensation, this order materializes in tangible structures. The larger is the number of irreversible condensation events, the greater is the amount of objectified structural order.

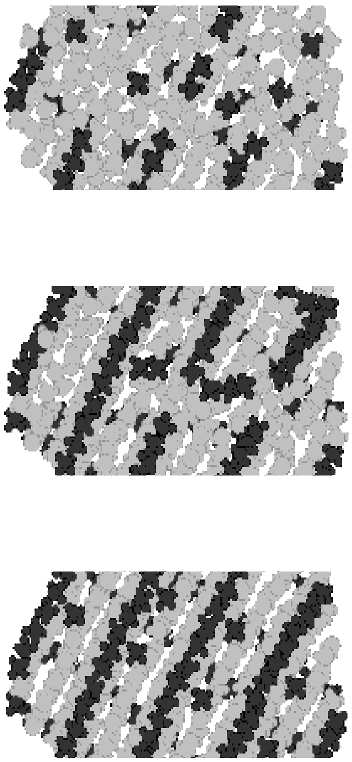

Fig. 5. Condensing water-based animate body at the molecular scale. Accumulation of ordered organic condensates orders the body.

4.3 The measure of evolution

The orderly condensation explains the emergence of more complex — and more diverse — forms of life. There is one additional effect known as evolution.

Evolution implies emergence of more advanced living species. But what does “more advanced” actually mean? The organisms that occupy higher levels of evolutionary development are supposed to be more efficient in surviving in complex and hostile environments.

It may happen that the “level of perfection” has a measure at the atomic and molecular scales as well. The organism’s “working body” may evolve into something more advanced.

Here is my hypothesis. The organism’s working body takes a step up along the evolutionary scale when it achieves a higher level of organization. It means that its atomic, molecular and mesoscopic transformations diminish mutual conflicts, enhance cooperation, and create larger ensembles. The working body enhances the agreement between its active agents. Correspondingly, it executes more complex, more extensive, and better coordinated actions.

In measurable physical terms, better-organized animate bodies reach higher degrees of chemical condensation: The superior organisms produce better packed condensates with better (more energetically favorable) chemical bonds. They increase the degree of processing of raw materials; meaning that they transform initial precursors into more intricately arranged products. They get more efficient in harvesting the abilities of the atoms to perform ordering actions.

At the macroscopic scale, more advanced organisms become more productive, and, therefore, more competitive. They increase their chances for survival. Animate matter always strives to evolve. The root cause of evolution is the ordering chemical condensation. However, it does not know how to do it. It takes a lot of trial and error to find superior configurations. For this reason, in ecosystems, evolution is caused by mutations, competition between different organisms, and natural selection.

4.4 Primordial water-based organisms

Now let us go back in time. The earliest organisms must have had much lower degrees of condensation. They had simpler metabolisms. The earliest organisms contained smaller amounts of organic compounds; and those compounds had lower molecular weights. The organic condensates, produced by the first organisms, were less ordered, and formed poorer ordered arrangements. It means that the earliest animate matter was exposed to greater numbers of random processes, and implemented less accurate actions. In other words, *it was much closer to the inanimate state*.

On the bright side, due to the lack of guiding structural components, the primordial organisms could modify their internal structures during their lifespans. Almost certainly, they were capable of very fast evolution.

4.5 Contemporary cells

Perhaps, contemporary biological organisms contain less water and more organic components; these organic components have higher molecular weights, and are better packed. The advanced cells fabricate a wider range of molecular products, and build more intricate structures from these products.

The superior organisms execute more elaborate and more accurate actions at the molecular and atomic length scales. They can synthesize increasingly complex compounds with higher precision. *In brief, through evolution, animate organisms get farther away from the inanimate state.*

4.6 The history of DNA

In my opinion, DNA is a very complex product fabricated by very complex and well-organized cells. The cells capable of making DNA accomplish very deep chemical transformation of raw materials. They implement very precise manipulations of matter at the atomic scale. To reach such levels of precision, complexity, and organization, the cell had to go through a very long process of evolutionary development, which could take billions of years. The RNA and DNA molecules must have emerged at some point in this long process.

Additionally, the evolution of living organisms goes hand in hand with the evolution of their habitats. Remember that organisms reorganize their habitats in ordered ways. These changes also accumulate with time. The changes of the habitats, in return, affect the living organisms. Usually, the habitats get more complex and more diverse. The increasing complexity of habitats stimulates the development of ecosystems. The process of evolution escalates and gains speed.

In order to explain the origin of DNA, one needs to trace the evolution of living organisms and their habitats over very long periods of time. This process involved a colossal number of elementary irreversible events. No computer can calculate it. I am afraid that the exact history of DNA — or any other glorified component of modern cells, for that matter — will remain obscure forever.

On the other hand, one could partially reenact the evolution process experimentally using artificial animate matter. The thing is, the production of artificial animate beings will involve evolution and artificial selection rather than intentional design. As a matter of fact, I have plans to conduct this reenactment. I currently raise funds for this cause.

5 The Origin of Life

In the final part of the paper, I talk about probable origins of life, and describe the blueprints of the simplest organisms. Fair warning, these organisms will be very different from familiar biological cells.

5.1 The entanglement

In this paper, I have argued that a living organism is a group of cooperating atoms that reconstruct their chemical bonds by organizing collective reconstructions of their common condensed matter body. The orderly collective reconstructions can only occur in specifically arranged bodies. As a rule of thumb, in usual materials, the elementary agents act at cross purposes. The bodies that cannot produce any orderly collective reconstructions will be called "entangled". To enable collective movements, they must be "disentangled". This disentanglement occurs in living organisms when they rearrange matter at the atomic and molecular scales.

The emergence of life corresponds to the appearance of the first disentangled body. I will discuss the spontaneous disentanglement shortly. But before I do so, I will explain how existing organisms disentangle themselves. This process was described in detail in my paper entitled "The Physics of Life. Part 2".[II] Here is a brief recap.

5.2 Collective rips

An autonomous action starts from a rip in the organism's body, in which many chemical bonds break one after another. The ripping resembles a break of a dam. The broken bonds eliminate some internal constraints. The removal of the constraints activates a new batch of inhibited agents. They rock the body and open the rip further. As a result, the rupture expands in an avalanche-like mode.

The action ends when the body begins to restore the broken bonds. The healing of the rip may also resemble an avalanche, when one restored bond shrinks the tear, and triggers formation of next bonds.

The spontaneous rupture of the animate body is the simplest case of disentanglement. The healing of the rupture corresponds to the simplest entanglement. Therefore, the living body constantly entangles and disentangles itself. The entangling corresponds to the inhibition, whereas the disentangling corresponds to the activation of the animate body.

Generally, any condensed matter body containing a significant amount of unsatisfactory chemical bonds has a desire — and a potential capability — to disentangle itself through spontaneous ruptures. In favorable circumstances, such bodies could trigger spontaneous collective processes. However, the probability of such events depends on the degree of entanglement, and in many situations remains small.

5.3 Emergence of an organism in weakly entangled systems

Consider a weakly linked body that makes spontaneous ruptures and produces collective reconstructions. Each of these reconstructions will bring it to a new configuration. In a series of reconstructions, the structure of the body will change, like a kaleidoscope pattern. Generally, after several reconstructions, the body will change beyond all recognition.

However, not all reconstructions change structures out of recognition. Some special arrangements generate reconstructions that bring the body to the "almost original" formation. In other words, the configuration of the body after the reconstruction will closely resemble the configuration before the reconstruction, only composed of different elements. These special reconstructions simply replace some used elements with fresh equivalent elements. Consequently, the specially constructed bodies will repeat the same reconstructions over and over again.

In my paper entitled "The Physics of Life. Part 1", I called these special arrangements "recurring configurations"; they produce "recurring reconstructions".[I] I have also argued that these specially arranged bodies correspond to biological organisms. Indeed, biological organisms periodically generate similar actions. These actions restore the structure and function of the organism. A more detailed discussion of this issue can be found in my manuscript entitled "The Physics of Life. Part 3: The Artificial Animate Materials".[III]

The general structure of the organism will be described in the following sections. Here I explain the emergence of the first organism. The aimlessly evolving material body described at the beginning of this section may undergo modifications, try many different configurations and eventually find one of the recurring states. As soon as it reaches such configuration, it will establish the recurring reconstruction, and reinforce it by repetition. In my opinion, this particular course of events describes the emergence of life. The whole process is driven by the collective condensation. However, it does not involve aimed self-organization. Instead, it is a trial-and-error process.

One important note should be made here. The original aimlessly transforming animate body has no goal and attains no specific objective. The organism, on the other hand, produces purposeful actions. Namely, it restores its own structure and function. The primary goal of the organism is its own survival.

In my paper entitled "The Physics of Life. Part 2", I have shown that the recurring reconstructions may further disentangle the organism and make it more complex.[II] In other words, the organism can grow and evolve. This happens because every reconstruction leaves a trace in the living body, and these changes accumulate with repetition.

5.4 Emergence of life in model systems

I demonstrated the spontaneous emergence of life experimentally. The results were described in my papers entitled "The Physics of Life" (Parts 1, 2, and 3).[I,II,III]

My primordial organisms appeared in weakly-entangled chemically inhomogeneous condensed matter. In my experiments, a small disentangled region of such substance produced a specific self-sustaining chemical transformation, and a mechanical reconstruction. This "seed recurring reconstruction" had strong disentangling and ordering effect. It induced new transformations in its surroundings, and subjugated them by means of special signals. The disentangled region grew in size by incorporating these new transformations into an "organized system of transformations" (thus, the organism). Importantly, this condensed matter body periodically repeated similar reconstructions. Thanks to that, the organism maintained a stable structure and a stable metabolic network. Fig. 6 illustrates the growth of the organism.

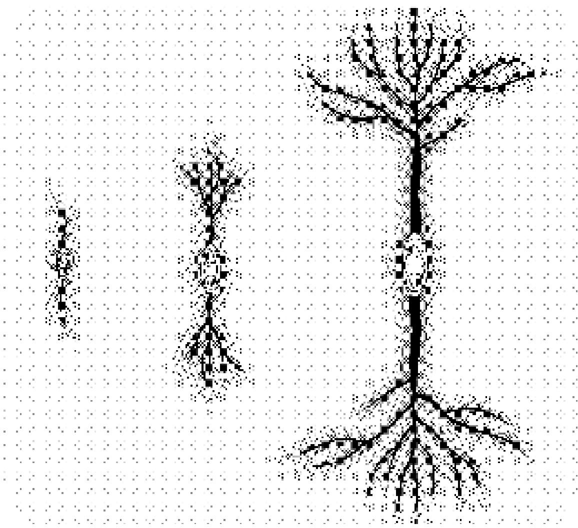

Fig. 6. The emergence and growth of the organism from a small recurring reconstruction. The seed ordering reconstruction disentangles its inanimate habitat. These changes accumulate over time. The disentangled parts of the habitat become parts of the organism.

My experimental demonstrations had one weak point. I used very simple non-biological materials instead of real biological matter:

In my manuscript entitled “The Physics of Life. Part 1”, I suggested that — in addition to real elementary living agents (i.e. transforming chemical bonds) — there are other, much simpler pseudo-animate agents.[I] Those have analogous properties, but much simpler behavior. The simplified agents are very convenient. However, they use other types of motive power. For that reason, these agents are not exactly “living” in the strictest sense. The real living agents, on the other hand, are too difficult to handle. I do not have the expertise to identify real primordial biological reconstructions.

5.5 The pseudo-animate granular matter

Now I briefly describe my pseudo-animate model system. Above all, in order to be “animate-like”, transforming condensed matter must generate non-random reconstructions. Many material systems have this property. The most common ones are hot cores of stars and planets. Their so-called “warm dense matter” produces planet-wide recurring reconstructions as evidenced by planetary magnetic fields.[18] However, there are much simpler examples. The simplest material system that generates non-random ordering reconstructions is the granular matter of the hourglass. (Fig. 7) It is composed of two types of elements: grains and voids. Under gravity, the grains aim to fall down, whereas the voids strive to rise up, like little bubbles. Being constrained by the walls of the glass, the grains make physical bonds with each other, and create a condensed matter body. The voids have the capacity to disconnect the grains, and destroy the condensed state. The tumbling grains hinder each other. The voids remove the obstructions, and facilitate motion. In short, the grains and the voids have opposite properties.

The flow of grains and voids in the hourglass makes a self-sustaining reconstruction as shown in Fig. 7. At the center of the funnel, a tumbling grain crosses the boundary between “the condensed matter body mostly composed of grains” and “the condensed matter body mostly composed of voids”. The material exchange is bilateral. It injects a new void into the jammed matter composed of grains. The void stimulates the recurring reconstruction that brings the next grain into the funnel. In the stream of the hourglass, the rising voids act as signals that permit motion. The tumbling grains may be regarded as feedback signals. The entire collective reconstruction realizes a circulation of these mobile signals.[I,III]

Simultaneously, the moving grains and voids act as mobile metabolites. The moving stream of the hourglass realizes a sequence of small pseudo-chemical transformations: The propagation of grains and voids involves stop-and-go motions. An unobstructed grain moves a short distance before it meets a new obstacle and stops. In each of these steps, a fraction of the grain is transformed into its opposite, and the rest goes further. Therefore, the stream of the hourglass can be regarded as a metabolic chain.

5.6 The simplest recurring reconstruction in a chemical system

A similar self-sustaining reconstruction can spontaneously emerge at a boundary between two substances with different chemical composition. A small section of this boundary can produce the reconstruction that implements the exchange of two moving metabolites as shown in Fig. 8.

When a piece of the first material crosses the boundary and enters new chemical environment, it triggers a certain chemical transformation, and creates another moving metabolite with opposite properties.

This new metabolite crosses the boundary in the opposite direction. In the first medium, it triggers another chemical transformation, creates the next moving metabolite, and sends it back to the second medium. Then the initial permutation of pieces will induce the next permutation of similar pieces, and the whole process will become self-sustaining.

Just like in the granular matter of the hourglass, the metabolic transformation of the moving metabolites may proceed in several steps as illustrated in Fig. 8.

Fig. 7. The active stream in the hourglass, which can be regarded as the simplest prototype and the mechanical analogue of an animate organism. Under gravity, the grains and voids become pseudo-animate agents. The seed recurring reconstruction appears in the funnel, where the grains and the voids trade places. The stream periodically brings the next grain into the funnel. Thus, the total reconstruction is self-sustaining. The separation of matter into the disentangled pseudo-organism and its entangled (jammed) habitat exemplifies the emergence of life.

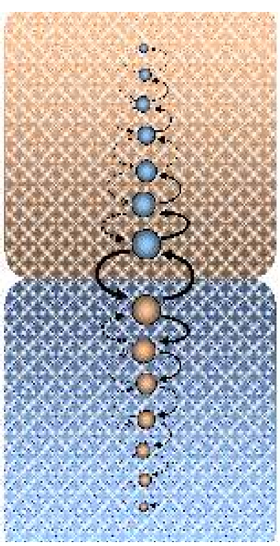

Fig. 8. Self-sustaining recurring reconstruction at the boundary between two media with different chemical composition. The metabolites cross the boundary, and then turn into their opposites through simple metabolic chains consisting of several steps.

5.7 The exchange of metabolites between the organism and habitat

The boundary between two chemically different substances could be regarded as the border between the primordial organism and its habitat. (Fig. 9) The exchange of metabolites across the boundary could be viewed as feeding. The metabolic chain of the organism generates a special signaling metabolite and injects it into the environment. In a chemically suitable habitat, this metabolite must cause a particular chemical transformation, and create a specific response metabolite that must get back to the organism. In this way, the organism can sustain its uninterrupted activity by feeding. As soon as the organism digests one serving of food, it requests the next serving. *In my opinion, this particular process is the true essence of life.*

I contend that Fig. 9 is the blueprint of the simplest living organism in the simplest habitat.

The blueprint of a living organism must contain: (1) the structure and chemical composition of the organism's body; (2) the structure and chemical composition of its typical habitat; (3) the characteristic movement of metabolites, and their chemical and structural transformations, in the body of the organisms and in the body of the habitat.

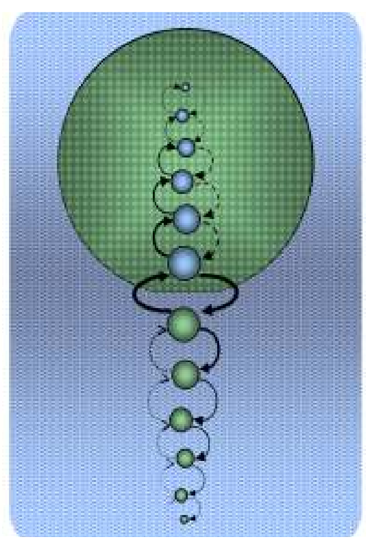

Fig. 9. The simplest organism in the simplest habitat. The single metabolic chain of the organism generates a special signaling molecule and then releases it into the environment. The chemically suitable environment generates a response metabolite, which sustains the entire reconstruction. Thus, the organism feeds.

I define the simplest living organism as an animate condensed matter body that feeds by exchanging metabolites with its environment.

5.8 The simplest permanent organism

The simplest organism described in the previous section has a major flaw. It has a short lifespan because it needs to release its own matter into the environment.

A permanent organism may appear in a slightly more chemically inhomogeneous medium, as shown in Fig. 10. The organism must realize two different exchanges with its habitat. At one interface, it gets the first nutriment. In its own body, it transforms it into the first excrement by means of its own metabolic chain. It discharges this product as a signaling molecule at the second interface, and gets the second nutriment in return. This second nutriment is transformed into the second excrement. It is used as the signaling molecule that stimulates the habitat, and brings the next serving of the first nutriment. In this organism, the metabolites move in a closed loop; and this motion creates a self-sustaining circulation of signaling molecules. The organism undergoes a perpetual reconstruction; it cycles the habitat's material through its own reconstructing body.

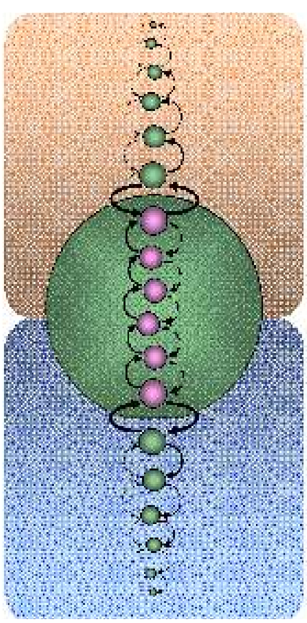

Fig. 10. The perpetual organism, which acts as an intermediary between two substances with different chemical composition. The organism contains its own internal circulation of metabolites, realizes two material exchanges with its habitat, and creates two different metabolic chains in the habitat. From two different interfaces, it obtains two different types of food, and emits two different types of stimulating chemical signals.

5.9 The reproduction of the simplest organisms

The permanent organism may accumulate material and grow in size. Additionally, it may create parallel metabolic chains as shown in Fig. 11. These chains may carry similar metabolites and produce similar reconstructions. In my paper entitled "The Physics of Life. Part 1", I showed that similar reconstructions interfere. They also tend to build impermeable borders. By doing so, they stop hampering each other. This mutual interference may eventually cause reproduction. The organisms' reproduction is NOT mere replication of molecules. It occurs when one self-sustaining reconstruction (one organism) releases a new self-sustaining reconstruction (an offspring organism). First, the organism grows and accumulates the interfering segments. Then these segments form a new self-sustaining circulation of metabolites. After this, the transforming body divides into two disconnected parts.

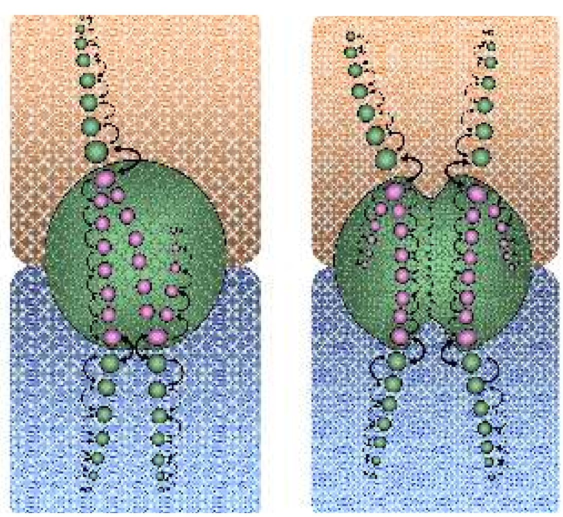

Fig. 11. Division of the animate condensed matter body caused by the emergence of a competing reconstruction. The two self-sustaining reconstructions build an impermeable border.

5.10 Collective organisms

On rare occasions, one can observe a phenomenon which is the exact opposite of the division. Two or more reconstructing bodies may combine into a single body and produce one common reconstruction. This happens when these reconstructions are fully compatible. Instead of interfering, they mutually enhance each other.

To establish a collective organism, different cooperating organisms must build material connections with each other, and create a common condensed matter body. This is accomplished with the help of condensation. Then the reconstructions must elaborate a common collective behavior by modifying the structure of their shared body. They must eliminate the disagreements (by building internal walls in the right places), and remove the isolating barriers between the cooperating parts. In principle, two different biological cells may fuse into a single cell. Perhaps, this happened when mitochondria became integral parts of complex cells, and when chloroplasts became organelles of algal cells.[19]

It must be said that full cooperation between different reconstructions is very rare. More commonly, different cells attain only partial cooperation. In this case, they create multicellular organisms. In a multicellular organism, every cell retains its own (partially independent) internal reconstruction. The collective reconstruction is created by making and breaking isolating barriers at the right places. The cells may also create an evolving multicellular condensate that changes its structure and function. That is the animal brain. The operation of the brain is described in my paper entitled "The Physics of Life. Part 2".[II]

5.11 The artificial collective organisms

In my papers entitled "The Physics of Life" (Parts 2 and 3), I described my experimental attempts to create the collective forms of artificial life.[II,III] At the beginning, I made individual animate forms that operated at an interface between two chemically different media as described in Section 5.6. Then I tried to combine them into cooperating ensembles and observe their collective reconstructions.

My proof-of-concept experiments were rudimentary as I used only the simplest available tools and equipment. They require thorough verification. Nevertheless, my efforts appear to have been at least partially successful. It is possible that, with proper development of materials and techniques, I will be able to fabricate complex forms of artificial life through this process. My final goal is to demonstrate their complex adaptive behavior.

Conclusions

At the end of this manuscript, I would like to discuss the practical utility of this work.

Firstly, this work is not a scientific discovery. It is an invention. In a nutshell, I invent a new aggregate state of matter from first principles.

The invention is based on experimental results, and, to the best of my knowledge, does not contradict any experimental observations. However, it introduces totally new concepts, and invokes several unsupported conjectures. The validity of this invention is not yet proven.

Secondly, the experimental validation of the invention will require vast resources and a significant amount of time. It may cost billions of dollars and the effort of thousands of researchers. The present invention may ultimately cause a major technological breakthrough in artificial intelligence. However, this would require the development of new branches of physics, biology, mathematics, and materials science. I will not be able to achieve all of this on my own.

As a regular practice, the scientific research supporting (or refuting) this invention will belong to particular institutions and R&D companies and not to individual researchers employed by these institutions. You will be able to award your prize to a particular person or a group, but most likely, you will be unable to acquire any intellectual property rights. This means that you risk getting nothing in return for your money.

All the foregoing does not mean that a group of individuals cannot invest into this invention today and secure a share of potential revenues from the entire prospective industry in the future: For now, I am the sole inventor of the invention. I am offering you an opportunity to purchase a share of the intellectual property rights. You can participate in the development of this innovation starting from the patent filing process.

By working in partnership, we can increase our chances of resolving the most important scientific problem of the 21 century. I admire your curiosity, and appreciate you desire to encourage technological and scientific progress. Your aspirations are very honorable as they may generate significant social benefits. In this situation, seeking a commercial profit is a perfectly legitimate additional objective.

These aims coincide with mine. Most importantly, I wish to draw attention of the scientific community to my invention, and guide it in a new direction. Financial incentives remain the most powerful motivators for scientists. The Evolution 2.0 Prize may become a very powerful tool for attracting attention of the academic community.

Prospective patents

First of all, I propose to patent artificial animate matter and the methods of its fabrication. I have already created a nucleus of a new R&D company, the main purpose of which is to develop artificial animate materials.[20]

The artificial animate materials will be made by injecting particular metabolites into inanimate condensed matter bodies. My experiments show that one can "breath life" into a sufficiently broad range of different compounds. Only, every material requires suitable metabolites. The production methods are similar to those employed in manufacturing of integrated circuits. The details are disclosed in my papers entitled "The Physics of Life", Parts 2&3.[II,III]

I would also suggest patenting "the principle of operation" of the animate bodies. In addition to the signaling system, I would patent the methods of elaborating consensus decisions by structural modifications of these bodies. This process is described in my paper entitled "The Physics of Life. Part 2".[II]

Finally, I propose to patent artificial intelligence devises made of the artificial animate materials. These autonomous robots will have their own independent wills, and will generate their own independent actions. They will perceive the reality, make decisions, and solve problems like real animate organisms.

Supplementary materials

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19 https://en.wikipedia.org/wiki/Symbiogenesis, https://simple.wikipedia.org/wiki/Endosymbiosis.

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