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Physics of Life. Part II: Neural Network as an Active Condensed Matter Body

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The non-equilibrium “active agents” establish and break bonds with each other and create an evolving condensed state known as the active matter. Here, the active agents are neurons, and the evolving condensed matter is the brain. This article describes autonomous reconstructions of this active matter. It explains how the neural network creates the mind. The author notices that the active condensed matter made of neurons is similar to that of the molecular bodies of folding proteins and molecular machines. He conjectures that they generate autonomous motions by the same rules. The paper describes voluntary motions of the simple molecular condensed bodies and discusses their interactions with an external environment. In addition to generating motions, the active bodies register external signals and correspondingly adapt their behavior. The active condensed matter bodies can memorize their own active motions and then reproduce those motions. It is shown that deliberate manipulations can transform initially inactive equilibrated condensed matter into the active matter. Based on this, the author suggests manufacturing artificial animate beings from the inanimate matter. These prospective animate forms would be much simpler than the real biological organisms. However, they could serve a useful purpose as “generators of the autonomous behavior”. They would make decisions and solve problems by the same rules as the real neural networks. Therefore, the synthetic active condensed matter could produce basic artificial minds.

Keywords: autonomous biotic motion, active matter, neural networks, physics of mind.

1 Introduction

A neuron is a biological organism that generates its own autonomous actions. In addition, the neuron registers external signals and modifies its actions accordingly; i.e. it may act in response to the signals. In the neural network of the brain, all these individual organisms unite into a single big entity and form a collective organism with new autonomous behavior. This paper explains how a collection of simpler organisms creates a collective organism. It also describes the characteristic behavior of the neural collective organism.

In Part I of this manuscript, the author defined the individual living organism as an active condensed matter body. It is a piece of structurally arranged condensed matter that implements a spontaneous reconstruction. The reconstruction could involve simultaneous or sequential events. In a single organism, all these events are connected e.g. by cause-and-effect relations. The reconstruction is driven by special structural elements of the condensed matter that undergo chemical transformations: The chemical transformations do not conserve volume of the structural elements. Therefore, they move the condensed body, and alter its structure. In particular, they alter the bonds between the elements. The transforming structural elements of the condensed matter were termed “the active agents”.

The collective organism arises when the simple organisms join their material bodies into a big common active condensed matter body. (FIG. 1) In this common material body, all the individual reconstructions join together and create a common coordinated reconstruction. In the collective organism, the local reconstructions corresponding to the previously autonomous organisms become the interdependent components of this big reconstruction.

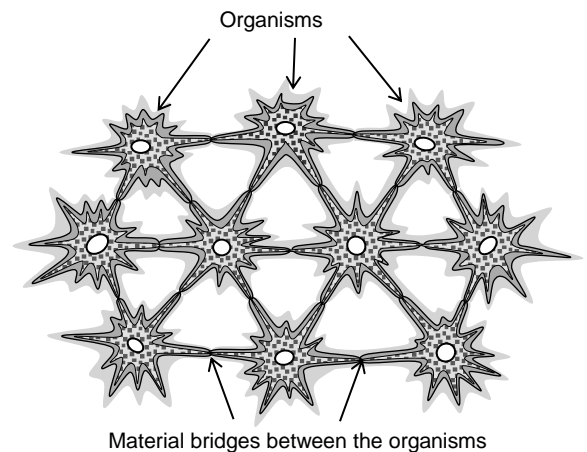


FIG. 1. Condensed matter made of the living organisms. The organisms have material bonds with each other.

The neural network carries out a special collective reconstruction. It may be described as follows.

In the neural network, the neurons periodically establish new- and break old material bonds with each other. Physically, all the neurons stay at their original places. Yet, their connections become rewired. This implies that the neurons rearrange with respect to each other: they commit permutations.

Each configuration of the neurons corresponds to a particular unique collective reconstruction. In each configuration, the neural network performs a distinctive task. Every permutation of the neurons changes the structure of the collective reconstruction; the collective organism begins to function differently. The rewiring continues.

Correspondingly, the neural collective organism changes its own structure like a kaleidoscope pattern. Since the number of different neural configurations is colossal, the brain can perform an immense variety of different actions.

Regardless of its incredible versatility, the reconstructing neural matter never evolves beyond recognition. Periodically, it returns to a certain “original configuration”. Moreover, the neural condensed matter tends to execute repeating sequences of actions or daily routines. It happens because during every permutation, the major part of the neural connections remains unchanged. The reconstructing neural matter can also evolve. It can learn, and perform increasingly complex actions. This implies that the neurons can grow completely new bonds and invent new ways of connecting to each other. The author will address these effects later in the text.

The immediate goal of the author is to answer a more important question: He wants to understand what controls the reconnections of the neurons. For the rational behavior, the reconstructions of the neural matter must be deliberate; they cannot be random or chaotic.

2 Evolving connections between communicating organisms

The author will first explain why, in general, simple organisms tend to connect to each other and create coordinated groups such as complex organisms. The answer to this fundamental question may come from the condensed matter physics. Part I of this manuscript argued that any living organism implements the process of chemical condensation. It builds the missing chemical bonds between its parts. When the living organisms seek to bond with each other, they simply continue the condensation process. The resulting complex organism is a larger condensed matter body with a larger reconstruction.

A larger reconstruction should have a faster metabolism. However, not all organisms unite when they meet. Usually, they strive to stand apart. It happens because their reconstructions destruct each other; they are incompatible. The conflicting organisms would get rid of the destructive bonds and even create protective barriers from each other.

In rare cases, the reconstructions of different organisms construct each other or “cooperate”. The cooperation manifests as the mutual enhancement of the organisms' metabolisms. The compatible organisms may create a common reconstruction.

Regularly, different organisms partially destruct, and partially construct each other. Therefore, they join the compatible parts of their reconstructions and detach the incompatible parts. As a result, they produce a collective reconstruction illustrated in FIG. 2.

The story does not end there. Every organism is an evolving system. It goes through different stages of its living cycle (or daily routine) and periodically changes its occupation. At different moments, the same bond between the organisms could transmit constructing- and destructing

influences. For this reason, the bonds between the organisms must be constantly re-wired: the connections that become destructive must be quickly eliminated, the new constructive connections must be installed instead.

Two communicating organisms should create a quickly evolving system shown in FIG. 2. They periodically establish new- and break old connections to each other. If the organisms' metabolisms cycle periodically, then the connections between them should cycle with a common period.

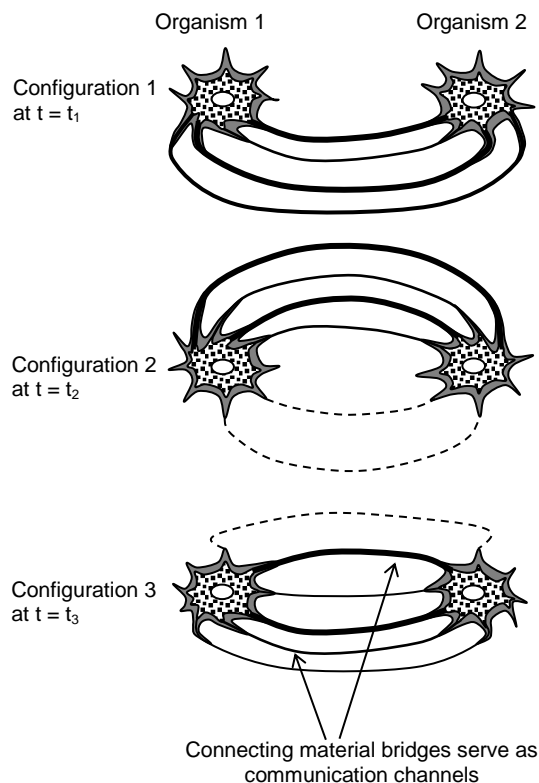


FIG. 2. The evolving condensed matter made of two organisms and their communication channels (material bridges). At different times the material connections are different.

Surely, not all cellular organisms are capable of accomplishing such difficult manipulations as periodic reconnections. For this reason, creation of complex multicellular organisms is rare. Apparently, the neurons are exceptionally good at reconnecting. Thanks to this remarkable capability, they showcase the proper collective reconstruction.

3 Establishing connections between the organisms

Establishing a new bond (or breaking the existing bond) between the organisms is not an instantaneous event. It is a long process that requires gradual adjustments of the organisms' metabolisms and structural alterations of the material bridges that link the organisms.

Figure 3 shows two organisms that come into contact via a material bridge. The active reconstruction of the first organism strives to move and rearrange the second organism. For simplicity, let us assume that these interventions are purely mechanical. I.e. the first organism attempts to perform transmutations of the atoms or the atomic clusters in the bridge and in the second organism. The bridge and the second organism resist the rearranging. Additionally, they hinder movements and reconstructions in the first organism.

Occasionally, the second organism yields, and allows a rearrangement. This implies that the first organism transmitted an information signal to the second organism: In the condensed matter, the ordered reconstructions, such as transmutations of the atoms, encode information. The transmission of the reconstruction from the generator of the reconstruction (the source) to the recipient is the act of communication.

In the recipient organism, the assimilated signal may stimulate the response reconstruction. The two organisms could then create a feedback loop with a positive reinforcement.

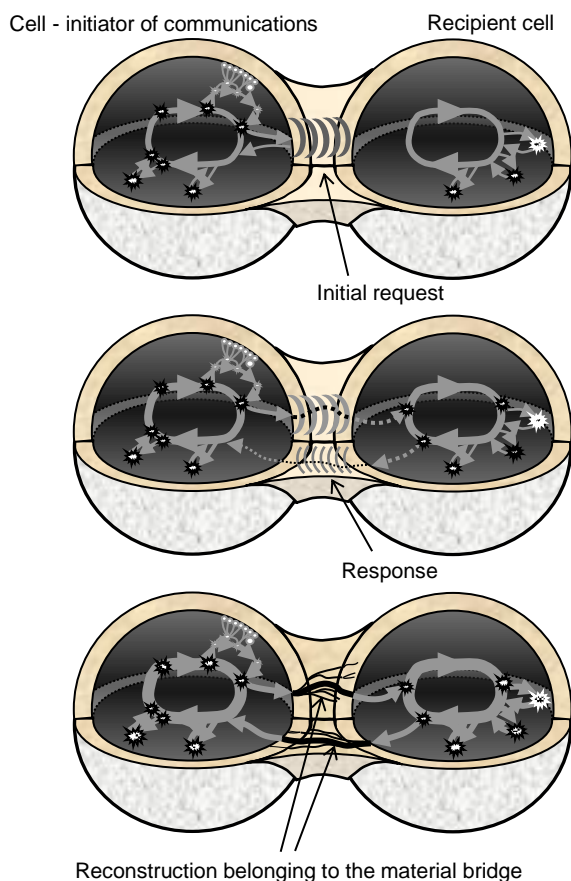


FIG. 3. The cell on the left attempts to connect to the cell on the right. After establishing communications, metabolisms of both cells enhance.

The mechanical motions with the increasing amplitude will eventually rearrange and soften the material bridge. The initially isolating barrier between the independent organisms would become apt to transmit particular types of mechanical motions.

The connections between the real neurons must be established in the similar way. They must be reinforced by the transmitted communications: The intensified communications between the cooperating neurons should strengthen the bonds and increase their carrying capacity. If the neurons fight, the corresponding destructive signals must eliminate the bond. The decision to produce a connection is made by both neurons. The neurons take into consideration the compliance of the material bridge.

4 Trial-and-error reconnections in the neural network

Let us first assume that the neurons grow new bonds completely at random. During communications, the neurons would determine whether those connections were constructive or destructive. They would retain the useful connections and dispose of the detrimental ones.

This trial-and-error method could work well for small neural nets consisting of several dozens of neurons. When the number of neurons increases, and the number of links between the neurons increases proportionally, the whole system would halt:

In large neural nets, the number of random trials to achieve a viable neural arrangement grows dramatically. It requires more resources and more time. The probability to find an appropriate configuration in a reasonable time diminishes catastrophically with the growing number of neurons.

The neural network must be able to quickly adapt to the changing environmental conditions. The trial-and-error adaptations would be completely inadequate for this purpose. It is known that brains consisting of billions of neurons quickly adapt. One is compelled to conclude that the neurons do not reconnect at random. Instead, they must follow specific instructions that come from all the other neurons.

5 Subordination in the collective organism

Indeed, in addition to reconnecting, the neurons exchange information signals. Let us consider the neural network sketched in FIG. 2.

In regard to subordination, the communicating organisms have a dual nature. On the one hand, they partially obey each other. On the other hand, they retain partial independence from each other. Subordination relates to the way the organisms generate commands:

When the organism makes a reconstruction, it generates information. It uses its own chemical resources for that purpose: The active agents undergo chemical transformations

and convert hidden chemical energy and order into the observable mechanical motions and structural alterations.

In the communicating organisms, a certain fraction of the chemically transforming agents is activated by the common part of the reconstruction. Another fraction of the agents is activated by the own, unshared part of the reconstruction. This independent generation of the commanding signals implies partial independence of the organisms.

There is one important special occasion. The common part of the reconstruction may effectively inhibit the independent actions of the organisms. Then the organisms will completely lose their independence. The communicating organisms will become a true collective organism. The common reconstruction that effectively suppresses independent actions of the organisms creates the collective enslaving agent.

The analogous effect should take place in the neural network of the brain. There, any given neuron should never excite on its own free will; it may only do so with the collective permission of all the other neurons. The common reconstruction of the neurons that inhibits or excites the actions of the neurons will be the controlling entity; it could be called the collective free will of the neural network. The next section explains how this entity emerges.

6 The collective free will of the neural matter

Here the author will make a very simple but important conjecture. He will assume that the neurons in the neural networks can relay received signals to other neurons.

Then, in a highly interconnected neural network, the signal from any given neuron to another one will travel along many different paths, including the paths that go through other intermediate neurons. (FIG. 4.) While travelling along the neural network, the signal exchanges information with the intermediate neurons. It activates or inhibits them, and changes their intentions to reconnect or commit a reconstruction. In turn, the neurons alter the signal, and mix the signals that come from different sources.

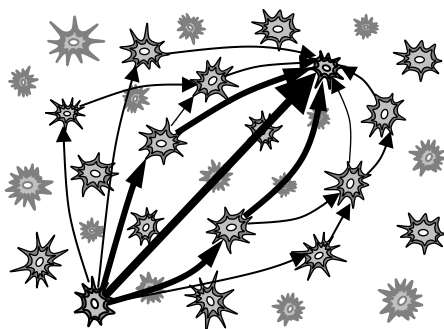


FIG. 4. Two neurons connected via multiple paths.

In the condensed matter made of neurons, all the information signals generated by different neurons mix, and connect to each other. They form the common entity that

could be regarded as the “condensed matter made of signals”. It will be termed “the collective signal”. The collective signal occupies the complete body of the neural network. The collective signal consists of a vast number of different components that affect each other. The neurons constantly produce and absorb new signals. Consequently, the collective signal quickly evolves by accepting and surrendering components. (FIG. 5.)

The collective signal and the neurons make a special active agent. It will be named the collective active agent. Indeed, it is the structural element of the matter that undergoes autonomous transformations. Only, this collective active agent is delocalized, it occupies the whole volume of the neural condensed matter body. This collective active agent generates the total reconstruction of the whole neural condensed matter. This collective agent has the collective free will.

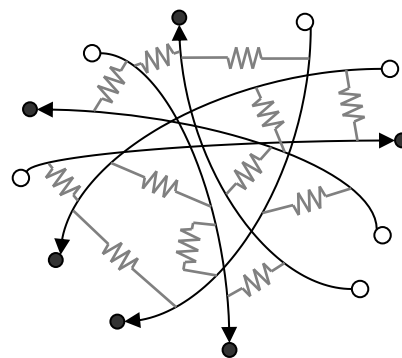


FIG. 5. The connected signals create a condensed matter made of signals. The links between the signals are represented by springs. These links also change in time.

This section articulated the first key idea of the manuscript. It should be reiterated as follows: In the relevant neural networks, the signals are not isolated from each other. Instead, they unite into a single entity and create an evolving condensed state. Behavior of the neural network is governed by the evolution of this condensed signal.

The second key idea of the manuscript will be stated in the next section.

7 Collective reconstructions of the highly interconnected neural matter

The real neural networks have a very distinct feature: it is a very large number of bonds between the neurons. For example, a neuron in a human brain may be simultaneously connected to up to ten thousand other neurons [1].

Growing number of bonds corresponds to further condensation of the neural matter. Its outcome might profoundly affect the behavior of the neural matter:

When the amount of bonds between the neurons increases, the neurons start receiving a lot of contradicting requests and become strongly frustrated. This will inhibit activities of the

neurons and hinder their reconstructions. The growing number of bonds bring about the effect similar to the transition of the matter into a different aggregate state: the matter transits from the agile and loose state to the state that reminds a solid. Nevertheless, the activities of the neurons are not entirely inhibited. Therefore, this solid-like active matter still performs some constrained autonomous reconstructions.

The growing number of bonds greatly increases the amount of causal links between different events in the neural matter. Any particular cause acquires multiple consequences. Also, any consequence has multiple causes. It becomes impossible to tell apart the important and the insignificant causes. On first impression, the overwhelming amount of the cause-and-effect relations makes the description of this evolving system very difficult. In reality, in this solid-like aggregate state, plentiful constraints significantly degenerate and simplify the active condensed matter's motions.

The reconnections of the neurons in this solid-like active condensed matter could be illustrated by the following example:

In the highly-interconnected neural matter, breaking of one bond between the neurons drags the matter and causes the break of another bond. Instead of individual bond reconnections, the neural condensed matter will produce extended ruptures. This process reminds crack propagation in the solid matter. Similarly, the extended ruptures are closing like fastening a zipper: restoration of one bond pulls the matter and recovers the next bonds.

The base operating principle of the neural matter holds. It involves regular exchange of signals between the neurons and periodic reconnections of the bonds because of the changing cooperation conditions. This time, however, the reconnecting becomes the collective effect. The decision on the rewiring of a given neuron is strongly affected by the collective agent.

This brings about the profound change in the abilities of the neural matter: The collective agent now can coerce the disagreeing neurons into performing actions that they do not want to perform. Moreover, the collective agent can inflict permanent structural modifications in the neurons. The neurons will undergo the "conversion training" under the influences of the collective reconstructions of the active condensed body. The neural matter as a whole acquires ability to memorize its collective actions and then reproduce the memorized actions.

8 The mind and its actions

The condensed matter made of the highly interconnected neurons reconstructs as follows. Instead of individual reconnections of the neurons, it spontaneously produces an extended rupture, rearranges, and then closes the rupture and restores the bonds. It does it on its own free will. Additionally, the decisions to make a collective reconstruction can be affected by some external influences.

In the jammed neural matter, the rupture produces the region with the least number of constraining bonds between

the neurons. Consequently, most of the transformations will be localized in the area of the rupture.

One should assume that the neural matter is somehow organized and ordered. Then the action produced by the ordered rupturing will also be organized and ordered. In this coordinated action, all the participating neurons will act jointly, as a coordinated team. All the elements of the extended action will be linked by the cause-and effect relations.

The following picture is beginning to emerge: the collective agent of the neural matter initiates and terminates ordered coordinated actions and controls their courses. It makes the decisions on which particular action to perform in the current circumstances. In this manuscript, the author will argue that this collective active agent could be regarded as the "mind" of the neural network. The author will define the mind as a living collective entity with the following characteristic behavior. It registers large quantities of the external stimuli. It perceives them as a coherent picture. Most of the time, the mind suppresses its own willed actions and responses. Occasionally, it would excite, and perform a particular coordinated action. Then, on its own volition, it would return to the initial quiet state.

This completes the first part of the manuscript. Here the author briefly described his conjectures regarding the neural networks' principles of operation. Immediately below, the author will proceed to more detailed explanations. Toward the end of the manuscript, the author will make an important conclusion: The solid-like jammed neural matter can be replaced with a particular artificial substitute. This substitute will employ the solid-like active condensed matter made of atoms that reconstructs via self-rupturing and reconnecting.

9 Mechanism of the spontaneous rupturing

In the quiet state, numerous constraints suppress the collective active agent's activity. Nevertheless, the neurons belonging to the collective agent are not dead; they produce some restrained reconstructions and accumulate energy. Additionally, the collective agent is affected by plentiful external signals.

These internal and external influences may produce fluctuations in the density of bonds: the neural matter may produce a small hole in itself. The removal of the constrains in the local area of the neural matter awakens some of the inhibited neurons. It must be noted that the excited neurons are scattered everywhere across the neural body. It happens because the local rupture is connected to all localities of the well-interconnected neural matter. (FIG. 6.)

Generally, different neurons in different localities of the network have different intentions: Some of the excited neurons want to close the rupture by re-building the missing bonds. Some other neurons would want to expand the rupture by breaking some excessive (for them) bonds. In order to do something with the rupture, different parts of the collective active agent must reach a consensus. The reconstruction that

takes place around the rupture should coerce the disagreeing minority to cooperating.

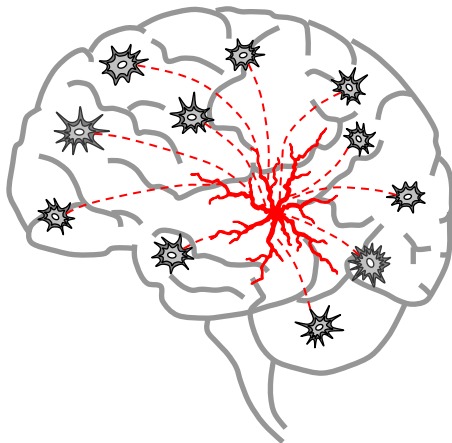


FIG. 6. The neurons connected to the rupture may belong to different distant parts of the brain.

Suppose that the majority of the neurons want to break the bonds and succeeds in subduing the wills of the disagreeing minority. Then the rupturing and the excitation of the neurons engage in mutual stimulation. The rupture expands in an avalanche-like fashion. This process is analogous to breaking a dam by the flow of water: the active motion breaks the constraining barriers and expands the breach. (In the dam breaching case, all different parts of the water basin want the same thing. Specifically, they aim to fall down. The neural matter is different: there, the different parts of the flow may want to go in different directions. The majority must entice the flow to propagate in one direction.)

The neurons need to maintain a particular number of connections. The neurons that lost too many bonds change their intentions. Instead of breaking the bonds, they begin to form new bonds. At this moment, the collective agent changes its intention, and makes the decision to terminate the rupturing. The neural body closes the rip, and returns to the quiet state.

The rupture plays an important role in the constrained neural network. It connects all distant parts of the network and offers them a ground for negotiations. It is a place and means for converting the disagreeing neurons. The decisions to start or terminate the action are made by the reconciled mind.

10 Evolution of the collective signal during rupturing

In the quiet state, all the components of the collective signal are strongly connected or “glued together”. In other words, the condensed matter made of signals resembles a solid. Consequently, the amplitudes of the (contradicting) signals are very small. Communications between different parts of the neural network are inhibited.

The localized rupture decreases the number of the constraining links between the components of the collective signal. The avalanche-like expansion of the rip may trigger a “phase transition”: the condensed matter made of signals will transit from the solid-like state to a more loose state. The collective signal will separate into the less connected pieces. This will facilitate exchanges of information between different parts of the neural network.

Because of the high interconnectivity, the localized rupture unleashes communications in the whole neural network. The neurons across the network will work faster, and generate more signal. Larger the size of the rupture is, stronger is the excitation of the collective active agent.

11 Evolution of the neural matter during rupturing

The impact of the rupture on the neural net is illustrated in FIG. 7. There, the highly interconnected neural network consists of only two neurons. In the quiet state, the neurons are connected via a “gray mass” of numerous faint signals. All these signals may contradict each other. They are connected to each other and for this reason are very weak. They inhibit both neurons.

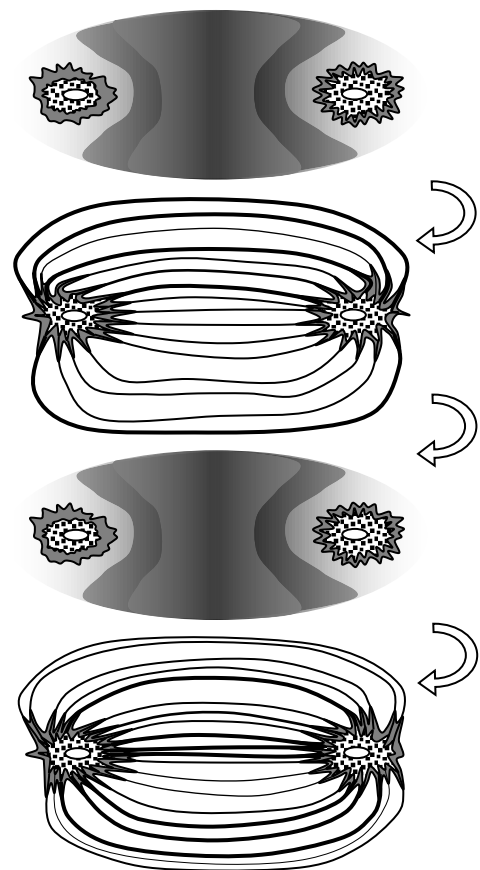


FIG. 7. Separation of the collective signal during the rupture. The neurons enhance the cooperating links, and eliminate the obstructing links. Equivalently, the neurons arrange into an ordered pattern and perform a big collective reconstruction.

During the spontaneous rupturing, this weak and disordered collective signal separates into the organized components. The destructive signals are eliminated, the constructive signals get enhanced. The “gray mass” made of signals becomes black-and-white.

At this moment, both neurons boost their activities. They create a firm common reconstruction and execute a certain collective action.

After the collective action is completed, the neurons decrease their activity, the communications between the neurons subside, and the signals stick together. Once again, the signals form the “gray” interconnected condensed state. The whole system returns into the quiet state. After a while, the system may spontaneously divide again. However, this could be a completely different rupture: The neurons will be reconnected in an alternative fashion. Then they will perform a completely different collective action.

12 Desires

In what follows, the manuscript explains how the collective agent decides how to rip the neural body and construct a particular collective action. Here it will be conjectured that the neural condensed matter is guided by its own desires.

A special characteristic could be assigned to the neurons. It is the desire to perform a certain individual action. For instance, a neuron may acquire a desire to grow a new material bond or to send a signal. Most of the desires remain unfulfilled because the neurons are obstructed by the neural condensed matter. The unfulfilled desires get subdued. On rare occasions, when the neurons get unlocked, their desires reemerge. In the yielding environment, the desire grows during performing the action. When the neuron satisfies its needs and depletes its energy, the desire disappears.

The collective agent communicates with every local neuron. If both the collective agent and the local correspondent satisfy their desires, the communication proceeds with the positive feedback, and these actions gain strength. Otherwise, they are curtailed.

Building the bonds is hard work. The neurons must spend substantial energy for that purpose. Overall, this process is equivalent to surmounting obstacles or forceful barrier breaching. Additionally, the disagreeing neurons must be coerced into cooperation. Therefore, in addition to the desires, the collective organism has strong reluctance or unwillingness to perform any action. It should not be forgotten that the condensed body has a lot of neurons that want to heal any possible rupture, and stop any active process. Any activity always battles with the desire of the neural body to inhibit any active process.

13 Principles of the decision making

Taking into consideration all of the above, one could formulate the general principles of the decision making. The

collective agent will take its next action according to the following rules.

Above all, it will choose the action that it is the least reluctant to perform. It is the action that is prohibited the least. Simultaneously, it will choose the most desired action. Therefore, the collective agent will elaborate a compromise between the path of the least resistance and the greatest satisfaction. Intrinsic desires could be triggered by the external influences. The collective agent may also have to react to the most urgent external call.

During generation of sequences of actions, the collective agent will first pick the actions that require the smallest investments of energy and produce the fastest positive results. After the easiest options are expended, it will switch to progressively more difficult actions. Evidently, the collective agent’s behavior is rather sound and reasonable.

If the collective agent had to choose between several alternative actions, it would choose the action with the greatest positive feedback (provided that this action inhibits its competitors most efficiently). If two local actions were in conflict with each other, the one that grows faster would win, and another one would get inhibited. If, instead of competing, two actions cooperate, they will be executed simultaneously creating a complex coordinated action. (The complex actions arise when different “body parts” of the active condensed body move simultaneously in a coordinated fashion.) During execution of a particular action, as soon as the positive feedback declines, and an alternative action starts producing a greater satisfaction, the collective agent “loses interest” to the initial action and switches to the new task.

The collective agent has a strong desire to terminate any action during its execution. When the action starts to bring back a lesser satisfaction, the desire to stop will win. The collective agent may abandon the action unfinished and progress to another more satisfying or urgent action. It may return to the abandoned action at a later time.

14 Predicting the observable behavior of the collective agent

Predicting the next decision of the collective agent would require an exhaustive knowledge about all the current active processes, the desires, the barriers, and the causal relations. This problem is unsolvable by any possible means: even the smallest neural networks have too many elements. The system is described by an unmanageable number of changing parameters. Besides, these systems do not allow any reduction of variables: any particular event or a causal relation may be important for determining all the following events.

Only the neural condensed matter body itself may resolve this problem, exclusively by executing the action. The collective agent itself cannot predict its own actions. By its own reconstruction, it “calculates” only the immediate next step.

Regardless of the aforesaid, there is a special kind of the active condensed matter which behavior could be predicted. Only, those predictions are not calculated. Instead, they are derived from the empirical observations of the earlier decisions of the active condensed matter.

This possibility is based on a particular property of the active condensed matter: The reconstructions of the matter do not produce its structural makeover beyond recognition. Instead, during the reconstruction, the condensed matter brings itself to a configuration that is very similar to its initial state. Consequently, the active matter can repeat similar actions multiple times. Part I of this manuscript named these configurations the recurring states.

In order to produce the recurring reconstructions, the active condensed matter must have a specific composition and a specific turnover of the desires of the active agents. Basically, the active matter must contain multiple equivalent elements that can perform equivalent tasks. For instance, the neural network must contain multiple interchangeable neurons. The work of only one of these neurons should suffice for the execution of a particular action. After executing the action, the used active agents should be replaced by the equivalent fresh agents with similar desires. The reader is referred to Part I for details.

Any biological condensed matter has this important property. Thanks to this quality, the real organisms have stable structures that they could retain during their whole lifespan. The following description sticks to that particular case.

15 Complex predictable actions

Let us consider a very well ordered neural condensed matter where the neurons are arranged in the ultimately precise orders. This well-arranged neural matter is deliberately streaked with the “easy tear lines”. The active body would prefer to rupture along these lines. Every easy tear line produces a particular rupture and realizes a specific ordered collective action. (FIG. 8.)

In some measure, the knowledge about the existing easy tear lines allows the external observer to predict the actions of the active neural matter. The internal desires of the neurons would remain unknown. Therefore, the external observer will never predict the decisions for sure. But he will know the list of available actions that the collective organism could choose from.

The size of the rupture determines the scope of the action. In a well-arranged and well-segmented active condensed body, the scope of the action could be quite large. During such actions, many parts of the cerebral neural matter become excited and actuate multiple body parts in full coordination.

The neural body may also be strongly entangled (disordered) and contain no lengthy “easy tear lines”. In this case, it would produce only small ruptures. The neural body would execute series of more constrained, less graceful actions.

The entanglement of the neural condensed matter could be so strong that the neural body would be able to produce only very primitive actions.

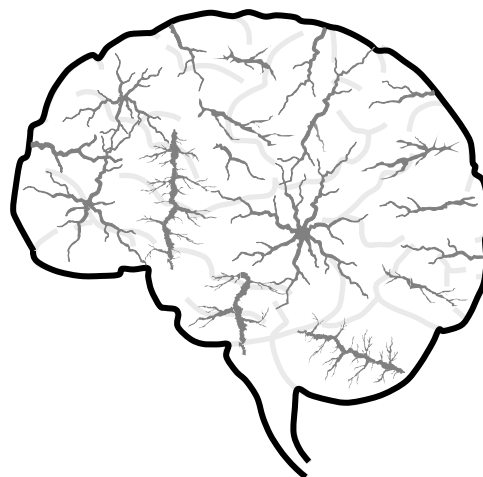


FIG. 8. Easy tear lines. The neural matter may rupture in several alternative ways. Every unique rupture corresponds to a particular ordered collective reconstruction.

16 Disentanglement of the entangled neural matter and production of more complex actions

The entangled neural matter may get sophisticated and extend, diversify, and develop its actions. The disentanglement is done by practicing, i.e. by repeating the actions for many times. This important ability is based on two characteristics: ability of the neural matter to memorize the actions, and its ability to extend the tear lines. In other words, the recurring states are not completely recurring. They slowly evolve with repetitions. Let us explain.

After an “easy tear line action” is finished, the rupture gets healed. However, the restored bonds differ from the original ones. It happens because the neurons rearrange during the action. This remains true even for the recurring actions. They differ to some small extent.

In particular, the action may weaken the stitches that close the easy tear line. Then this easy tear line increases its chances to be repeated in the future. In other words, the executed actions would be memorized by the matter.

In addition, the actions may also extend and get more complex because the tear lines may grow in size. This effect is similar to breaking of a river dam by the flow of water: The flow through the rupture may expand it.

Multiple repetitions of similar active processes will rearrange, order, and segment the condensed body. This disentanglement could proceed without any external intervention. In such case, it corresponds to self-learning. However, finding a good new rupture and creating a new easy tear line (i.e. inventing a new useful skill) is very difficult. It requires multiple unsuccessful tries; it might be very time-

and energy consuming. The most effective disentanglement requires the guidance of an external trainer. It would involve repeated reward-penalty communications and developing complex skills from simpler ones.

When the condensed body acquires partitions by means of the easy tear lines, the cause-and-effect links between different events decrease in number. The disentanglement separates the events into the related and the unrelated ones. There will be important and unimportant causes and effects. There will be essential and insignificant processes.

17 Recognition as a complex action

Let us consider interactions of the disentangled neural organism with an external environment. The active neural matter body may assimilate the whole collection of the external influences and produce one big integrated rupture in response. Then it is possible to say that the active neural matter body perceived these external influences as one complex signal in which all of the components were connected to each other. That is recognition. The complex disentangled organism has a fundamental ability: it can recognize and assimilate complex information.

Very often, the structure of the active condensed body does not allow recognition of the excessively complex signals. Correspondingly, the active body will be unable to react to them in a complex way. In such case, the reaction of the active body will be separated into a series of simpler ruptures or recognition events. During each event, the body would assimilate only a fraction of the complex information and generate a certain response. Recognition and assimilation of information sequentially, in small portions is very typical for the living organisms in general. Very often, the process of assimilation implies bilateral communications with the external correspondent.

Assimilation of complex information requires adaptations. Those are slight modifications of the ready-to-execute actions. Receiving the exact signals that would ideally match the easy tear lines of the condensed matter body is unlikely. In order to perceive the complex signal, the body must slightly alter its rupture pattern. Simpler the conveyed message, easier it is to digest.

Bilateral communications with the outside world stimulate the disentanglement described in the previous section. Thanks to this process, the neural body elaborates new advantageous responses to the previously unknown signals. This process could be understood as the problem solving. After the appropriate response is elaborated, the neural condensed matter body tends to reproduce it automatically. It may slightly adapt it to the current circumstances.

A particularly strong external influence may coerce the entire organism to executing an action that it does not want to perform. It may restructure the body of the organism using a brute force. It happens, for instance, when a virgin and entangled condensed matter body encounters a particularly

strong signal that it cannot assimilate. In this case, the overpowering external forces would make absolutely new rips in the body. The condensed matter body would resist as much as possible. This violent event could destroy the body and kill the life. Alternatively, if the rips could be healed, and the body could regain its operability, the body would learn completely new skills.

18 Atomic counterpart of the neural condensed matter

This section begins the concluding part of the manuscript. It addresses the topic that was announced in the abstract. Here, it will be conjectured that the neural condensed matter may have a simpler natural counterpart.

Reconstructions of the neural condensed matter could be compared to the spontaneous reconstructions of the subatomic protein bodies and molecular machines [2]. A molecular machine is a piece of the atomic condensed matter that tends to condensate (i.e. establish missing chemical bonds between its atoms) or decondensate (i.e. remove excessive chemical bonds between its atoms). In this respect, its atoms (or its atomic clusters) are the active agents that emulate the desires of the neurons. This condensed matter have significant amounts of already existing chemical bonds; those constrain further reconstructions of the condensed body. One might say that the constrained body of a molecular machine is in a distinct aggregate state of matter. On the one hand, it approaches the solid state; and on the other hand, it still reconstructs. The amplitudes of these reconstructions are very small. At any given moment, the majority of the possible active agents remains strongly inhibited.

The atomic condensed matter of the molecular machine could be heterogeneous, and be prone to condensation and decondensation simultaneously. For this quality, it should contain different atomic clusters: some of them should want to establish the bonds, and others should want to break the bonds with other clusters. Then, this matter will exhibit behavior similar to that of the neural matter: Intermittently, it would spontaneously escape from the constrained quiet state, excite, and perform a significant rearranging. Then, on its own volition, it would return to the quiet state:

The spontaneous self-excitations emerge when some of the active agents establish positive feedback communications with other agents. Mutual stimulation enhances the amplitudes of the atomic rearrangements. These rearrangements destabilize and loosen the condensed body. They rupture the matter. The ruptures eliminate constraints and remove inhibition from some additional agents. Thus, the ruptures and the active agents engage in mutual stimulation. This mutual stimulation compares to a break of a dam by a flow of water.

The ruptures destroy the internal bonds. *De facto*, its is decondensation. When the number of broken bonds rises above a certain value, the body becomes overwhelmed by the desire to condense and restore the bonds. At this stage, the active body stops rupturing, closes the holes in itself, and

returns to the quiet state. The burst of the activity associated with the rupturing registers as a distinct voluntary motion of the active condensed body.

The corresponding reconstruction is illustrated in FIG. 9. During the burst of activity, the active condensed body spontaneously produces and widens a hole in itself. Then it fills the created hole with a new material. One could say that the body partially turns itself inside out through this hole. During this motion, the rupture shrinks and closes. Then the hole is re-stitched with new material bonds.



FIG. 9. Spontaneous opening and growth of the internal rip in the condensed matter. The open rip is filled with an alternative material.

At the healed rupture, the restored bonds could become stronger or more numerous than the original bonds. The total transformation would then correspond to condensation of the body. Alternatively, the bonds could become weaker or less numerous than the original ones. This would yield decondensation of the body. In either case, the condensed body will retain memory of its active reconstructions. If the body produces similar (recurring) reconstructions, these changes will accumulate. Generally, the reconstructions will disentangle the matter. This will be explained in Section 20.

19 Signaling in the atomic active condensed matter

In this manuscript, the author argues that certain pieces (atomic clusters) of the atomic active condensed matter may act like neurons. It had just been explained that they can establish and break bonds with each other. Additionally, these pieces (active agents) stimulate each other and exchange signals. Indeed, the active agents produce ordered atomic reconstructions of the matter. Those carry complex information, and could be absorbed by other agents. The events of generation and assimilation of the atomic reconstructions change the intentions of the recipient active agents. In particular, assimilation of an atomic reconstruction could excite the active agents, and make them produce further actions. This could produce all sorts of feedback loops.

In a consolidated condensed body, all the atomic reconstructions mix and form the collective reconstruction (signal). The collective signal contains multiple interconnected components. The collective signal, together

with the participating active agents, form the collective agent that occupies the complete volume of the condensed body.

One should conclude that the active reconstructions of the molecular machines and those of the neural matter might be equivalent. The author conjectures that the neural matter simply emulates the voluntary actions of the molecular active matter. I.e. the subcellular active macromolecules are the prototypes of the neural matter of the brain. Both kinds of the active matter do essentially the same things: they generate autonomous reconstructions. Only they do that using different hardware, and on a different complexity level. The neural matter is more complex and produces superior reconstructions. However, in simple live artificial beings, the neural condensed matter can be substituted by the active condensed matter made of atoms.

20 Ordering and disentanglement of the entangled matter by the active reconstructions

A disordered (entangled) matter cannot produce organized atomic reconstructions and carry meaningful signals. In the entangled matter, the ordered atomic motions produced by the active agents will be transformed into a thermal noise. To perform considerable autonomous reconstructions, the atomic condensed matter must be orderly arranged. Desirably, the ordered body should be segmented by the easy tear lines. Then, during the reconstructions, the body would predictably separate into the less connected pieces that easily slide along each other.

For a macroscopic manufacturer, the exact manipulations of separate atoms presents a significant challenge. For this reason, the atomic condensed matter obtained artificially, without any biological templates, will be disordered, entangled, and motionless.

Section 16 suggested that the entangled condensed matter may be arranged and ordered (disentangled) after manufacturing. Also, this possibility was demonstrated in Part I of this manuscript using the hourglass example. There, the disordered jammed granular medium was rearranged by the active stream of grains. Generally, the entangled matter gets disentangled by the active ordered “seed organism” implanted in its body. The matter would gradually become reorganized by the repeatable and ordered reconstructions of this organism.

The entangled matter must contain plenty of potential active agents. Those should be activated by the seed organism. This requirement means that the matter must be prone to either condensation or decondensation. For example, the granular matter of the hourglass was prone to decondensation. Its disentanglement corresponded to accumulation and ordering of “decondensates” (voids). The active matter made of atoms must have the analogous capabilities.

Figure 10 illustrates the process of disentanglement of the matter prone to decondensation. The entangled condensed matter is implanted with multiple active seed organisms. Every seed organism rearranges its own part of the matter,

drags it, and involves it in its own ordered motions. The volumes of the organisms grow.



FIG. 10. Disentanglement of the condensed matter made of atoms. The seed organisms (originally independent reconstructions) resemble streams in the hourglass. They must rip and penetrate the matter, connect to each other, and create a common reconstruction.

During the disentanglement of the matter, initially independent organisms connect. At this very moment, they assume the role of neurons. They must create a common evolving reconstruction. One could apply the discussion of Sections 1-17 to these quasi-neurons, and repeat the reasoning without any modifications. After the active agents succeed in creating the collective organism, further disentanglement is done by the collective reconstruction.

21 Breathing life into the condensed matter

In order to obtain the active condensed matter one needs to take a piece of regular equilibrated condensed matter and populate it with some active agents. Loading a condensed matter with real chemical precursors and obtaining self-sustaining chemical reactions would produce real biological specimens. This task is difficult to attain in practice: one would need to find matching reactions and invent means of delivery for the chemicals. Animation of the condensed body could be accomplished in a much easier way. The energy to actuate the agents could come from external sources, like it is done in the neural networks. Indeed, the life support system is not the part of the neural network. Likewise, our animate condensed matter will live on the external life support.

The prospective condensed matter must be partially ordered. This will insure meaningful communications between the agents. Yet, the condensed matter must remain strongly constrained and entangled. The majority of the active agents must remain inhibited. The active agents must be able to rupture the condensed matter. It is the critical requirement since the experimenter intends to reproduce the autonomous rupturing effect. The condensed matter must be able to fill the holes, heal the rips, and return to the quiet state. The condensed matter must also memorize the ruptures. I.e. the healed rips must differ from the virgin material.

The prospective experimental system is illustrated in FIG. 11:

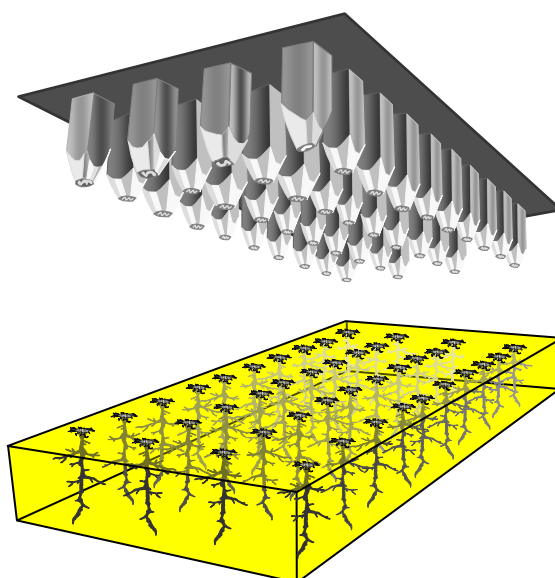


FIG. 11. Schematic representation of the active matter driven by the punch stamps.

A condensed matter bar gets stamped with an array of small precisely shaped punch stamps. Every punch stamp embosses a certain relief pattern on the bar. The punch stamps emulate the active agents that reshape their environment in an orderly fashion. Pressing on the punch stamp creates a system of internal rips and generates ruptures and controlled reconstructions of the matter. The condensed matter must be able to partially recuperate after removing the load: The embossed relief must fade away and the rips should get healed. The stamping must be periodically repeated to continue actuation of the matter. Repetitive stamping causes the system of healing ruptures to grow in size and complexity.

The cyclic plastic deformations create additional intrinsic active elements in the condensed matter; those are bond failures, active ruptures, propagating structural faults, etc. They order and arrange into patterns around the punch stamps. Roughly speaking, every such pattern corresponds to a neuron. One should require that the punch stamps were placed at certain separations from each other. Then the “neurons” first grow independently, then interpenetrate, intertwine, and unite into a single network. All the neurons unite into the collective active agent.

By this procedure, one would get a well-structured, well-trained, large “substitute of the neural network” which recognizes complex external signals and generates responses to those signals. An experimenter may want to divide the driving punch stamps (the sources of plastic deformations) into two groups. The first group would emulate the own periodic excitation of the neurons and generate the own internal activity of the condensed matter. The second group would correspond to the signals that come from the sense

organs. Then the active matter would react to the varying external stimuli.

22 The realized material embodiment

It turns out that both the material system and the experimental apparatus for populating it with the active agents already exist. The condensed matter bodies are the CD-RW (rewritable) discs, and the experimental apparatus is the usual CD-ROM drive. (FIG. 12.)

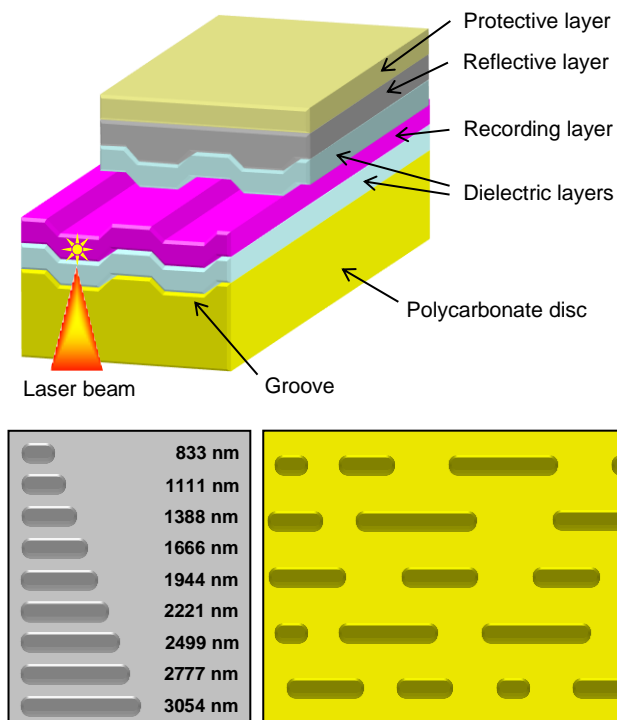


FIG. 12. Top: structure of the CD-RW disc. Bottom: burn pits produced by the laser during the data recording.

The CD-RW discs are used for repetitive recordings of digital data. During a recording, a very strong and focused laser beam produces an array of “burn pits” on the grooved surface of the disc.

The disc is composed of the polycarbonate plastic. It is coated with the special alloy thin film that absorbs the laser radiation and changes its optical properties producing the readable burn mark.

The recording inflicts the strong heating and the localized plastic deformations in the body of the polycarbonate disc. Therefore, every burn pit may be used as a punch stamp.

Altogether, the spiraling track of the disc contains about 10^9 burn pits of nine different lengths. (Nine different types of stamped patterns or nine different types of neurons). There are also spaces between the burn pits of nine different lengths. (The information on the CD is actually coded in these lengths.) They can produce a mind-boggling number of different combinations. The CD-ROMs are very precise: in

the repeated recordings of the same “disc image”, the same burn pits hit exactly the same spots (under the identical recording conditions). Therefore, one can repeat the stamping of the same places of the disc with exactly the same patterns, and make it periodic.

The multiple recordings cause structural degradation of the discs. These structural modifications manifest themselves via the misread burn pits i.e. the recording errors. They are detected by the same laser in the low-power reading mode. The error pattern becomes the *post factum* indicator of the reconstructions that took place in the disc during the recording. They could also be regarded as a documented “response” of the condensed matter to the active stimuli. The reading errors appear after several hundreds of recordings. Their number steadily increases until about one thousand of recording cycles. Then the experiments suddenly stop as the discs become unreadable.

23 Experimental results and discussion

The active condensed matter on the CD-RW discs was fabricated by the repeated recordings of the same “disc image”. This treatment implies that an invariable set of punch stamps emboss the disc one after another in a precise sequence.

When the first recording errors appear, they are chaotically distributed across the disc surface. However, as their density grows, they quickly agglomerate in patches of several millimeters across. With the increased number of recordings, these isolated patches expand, move and gather into larger patches. It appears as if the recording errors “cross-talk” and get attracted to each other. They tend to form a single patch or a single segment of the disc. During this process, the other parts of the disc get rid of their errors. Further recordings cause expansion of this error-populated segment until it covers almost the full surface of the disc. Shortly after that the disc becomes unreadable. This effect is demonstrated in FIG. 13.

This experiment was repeated for many times on different discs and CD-ROM drives, and using different burn pit patterns. The shapes and the positions of the error agglomerations were different. But the disproportionate distribution of the reading errors and their tendency to agglomerate on some segment of the disc was observed in all experiments.

The deviation from the proportional damage may be explained as follows: The misread burn pits might reveal the current position of the collective “rupture”. They might indicate the softest, the least constrained region on the disc, where most of the activity is concentrated.

If this supposition is correct, the experiment reveals how the initially isolated ruptures unite. The initially disagreeing “organisms” communicate and form a single coordinated organism. In this case, the whole disc may be regarded as a single active condensed matter body. It can produce a single

coordinated macroscopic reconstruction. Considering the size of the disc, this reconstruction might become very complex.

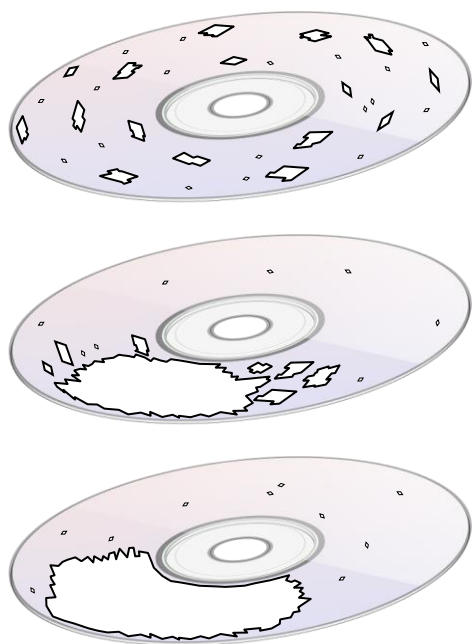


FIG. 13. Bunching of the reading errors on a particular segment of the disc. The size of the segment grows with the number of recordings.

This supposition is substantiated by the following observation: if the experimenter starts writing a completely new disc image, the segment almost completely disappears. The distribution of the reading errors becomes almost chaotic. Then, after about 100 burning cycles, the reading errors make a try to gather again and create a new segment in a different place of the disc. Sometimes they are successful, sometimes only in some measure. This depends on the quality of the disc and the amount of the reading cycles that it could withstand before becoming unreadable.

Recording of the new image on the old disc implies that a set of completely new punch stamps start populating the condensed matter with new rips. They destroy the old collective motion and start replacing it with a completely new one.

If the new burn pit pattern only slightly differs from the original, one may achieve a slight and relatively smooth change in the disc response. Generally, the fraction of the changed burn pits must stay below 2% of the original. Then the retrieved error patterns remain similar to the original ones.

Further results of this experiment will be disclosed someplace else. Here, they merely illustrate how the active condensed matter could be fabricated by the expedient means.

Conclusions

This paper, together with Part I entitled “Animate organism as an active condensed matter body”, devise a physicist’s perspective on the nature of life. Many earlier

authors undertook this endeavor. They employed non-equilibrium thermodynamics [3], theory of self-organization [4], complex systems theories [5], active and soft matter theory [6], evolving networks [7], and other disciplines [8, 9]. Up to this day, none of the authors came up with a fully satisfactory theory. These two papers formulate a new doctrine that should help to make yet another step toward the comprehensive physics of life.

Here, the fundamental notion employs the non-equilibrium active agents [10]. The cornerstone is the conjecture that these agents unite into a constrained condensed matter body. Life corresponds to the autonomous reconstructions of this active condensed matter body. The complexity of life depends on the order and the complexity of the active body. The discipline that should produce the adequate description of the biological phenomena is the dynamics of the active condensed matter.

Fundamentally, the spontaneously reconstructing condensed matter is described by the colossal number of parameters. There, a vast number of irreversible events is interlinked using a vast number of causal relations. In such systems, it is very difficult to reduce the variables. For this reason, the present manuscript is written in an unusual manner, uncustomary for physicists and mathematicians. It contains no formulas that would establish relations between a limited number of parameters.

The author believes that the adequate active condensed matter dynamics may be created with the help of archotyping. It is building the simplified working models of the condensed matter, when the real (very complex) body is replaced by another (much simpler) active body that performs a reduced number of actions. The model body should consist of simpler active elements. However, it should function in the similar way as the real biological prototypes. The archetype could be used for understanding the principles of operation of the biological organisms.

The author believes that the major cause of failures of other theorists in developing the physics of life originates from the erroneous reduction of variables. The existing standard methods yield good results only for those molecular systems that involve unrelated events and produce trivial dynamics of the elements, i.e. for gases and chaotic liquids. These methods become inapplicable for the evolution of the condensed matter (where all the events are linked). Nonetheless, the scientists persistently used them driven by the desire to employ the available mathematical tools.

The author emphasizes that any attempt to build the statistical mechanics or the thermodynamics of life before the dynamics will inevitably lead to failure.

On the other hand, the correct approaches to the reduction of variables make the statistical analysis of the spontaneously reconstructing condensed matter meaningful and informative. A good example of this success is given by the theory of evolving networks [11]. There, the active agents establish and break links with each other, and do nothing else. Regardless

of the oversimplification, this modern branch of statistical mechanics yields important clues about the spontaneously reconstructing networks. The author adapted several curtail ideas from this field. In particular, he adapted the notion of condensation [12].

Another example of the proper reduction of variables is population biology [13,14]. Up to the present day, this natural science exemplifies the most advanced quantitative description of life. The author was inspired by this science as well. In particular, he assimilated some of its terminology, such as competition, cooperation, etc.

Statement of intentions

Here the author makes the clear statement of intentions. He wants to create the theory of autonomous biotic motion and build the first absolutely artificial animate beings. He described his master plan and revealed the agenda for his future actions.

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The goal must be approached from two different directions. It involves building a theoretical and an experimental workbenches. Creating the theoretical workbench implies elaboration of the theoretical models of the active condensed matter followed by their computer simulations. Building the experimental workbench requires real material embodiments of the active condensed matter. These efforts must be carried out in parallel. They should feed one another with information and stimulate each other's development.

For these endeavors, the author seeks material funding. Also, the author reaches out to the interested enthusiasts asking for their involvement and participation. Without the external help the author will be unable to proceed from speculations and conjectures to solid proofs and experimental demonstrations.

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