13th International Workshop on Natural Computing (IWNC) @IS4SI 2021 - ABSTRACTS
https://summit-2021.is4si.org

FRIDAY, September 17, 4:00-12:30 UTC

TENTATIVE SCHEDULE OF PRESENTATIONS AND PANEL DISCUSSION OF THE 13th INTERNATIONAL WORKSHOP ON NATURAL COMPUTING (IWNC) IS DISPLAYED AT THE BOTTOM OF THIS DOCUMENT. PLEASE CHECK FOR POSSIBLE UPDATES ON THE WEB PAGE

INVITED LECTURES (TO BE DELIVERED AT PLENARY SESSION OF IWNC):

Friday, September 17, 2021, 5:00-6:00 UTC:

Computing with slime mould, plants, liquid marbles and fungi

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Dynamics of any physical, chemical and biological process can be interpreted as a computation. The interpretation *per se* might be non-trivial (but doable) because one must encode data and results as states of a system and control the trajectory of a system in its state space. One can make a computing device from literally any substrate. I will demonstrate this on the examples of computing devices made from slime mould *Physarum polycephalum*, growing plant roots, vascular system of a plant leaf, mycelium networks of fungi and liquid marbles. The computing devices developed are based on geometrical dynamics of a slime mould's protoplasmic network, interaction of action potential like impulses travelling along vasculates and mycelium networks, collision-based computing of plant roots' tips and droplets of water coated by hydrophobic powder. Computer models and experimental laboratory prototypes of these computing devices are presented.

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Friday, September 17, 2021, 4:00-5:00 UTC:

Machines computing and learning?

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A recurrent subject in automata theory and computer science is an interesting problem about how machines are able to work, learn, and project complex behavior. In this talk, particularly I will discuss how some cellular automata rules are able to simulate some computable systems from different interpretations, it is the problem about universality. These systems are able to produce and handle a huge number of information massively. In this context, an original problem conceptualized by John von Neumann from the 40s years is: How primitive and unreliable organisms are able to yield reliable components? How machines could construct machines? In biological terms it refers to the problem of self- reproduction and self-replication. In our laboratories, implement these problems in physical robots, where some particular designs display computable systems assembled with modular robots and other constructions display collective complex behavior. Modular robots offer the characteristic to assemble and reconfigure every robot. In Particular, we will see in this talk a number of robots constructed by Cubelets to simulate Turing machines, Post machines, circuits, and non-trivial collective behavior. We will discuss if these machines learn and develop knowledge as a consequence of automation and information.

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Moderator's Introduction to IWNC Discussion
"Natural Question about Natural Computing"
Marcin J. Schroeder

The panel discussion is scheduled on Friday, September 17, 6:00-7:00 UTC within the plenary session for IWNC after the two Invited Talks.
Panelists will be announced after they confirm their participation.

Introduction

The question about Natural Computing may be natural but the attempt to answer it by providing a formal definition would be pointless. Definitions of concepts serve the purpose of closing them into an existing framework of concepts with the already established intention or meaning. Natural computing is an open idea that serves the opposite purpose to transcend the currently dominating paradigm of computing. The qualifier "natural" that for centuries was a subject of philosophical disputes is used here not in the restrictive sense. After all, its common-sense negation "artificial" is associated with human skills or competencies which there is no reason to consider non-natural or at least inconsistent with human nature, human inborn capacities.

This conference is the 13th in the long series of International Workshops on Natural Computing whose participants and contributors have had diverse ways of understanding this subject. However, there was never a risk of mutual misunderstanding and there is no such risk now. What was and is common and uniting in these diverse inquiries can be expressed as the search for dynamic processes involving information that have all or some characteristics of computing, but are different from it in the form and means of implementation, procedural description, intention, outcomes, etc. The adjective "natural" reflects the interest in natural processes studied in several different disciplines of science independently from any application in computing, but it did not exclude the interests in the dynamics of information in cultural, social contexts of human life. Just opposite, Natural Computing is an attempt to bridge technological interests with natural aspects of information processing to transcend the limitations of computing, including the limitations of its present applications.

The panelists represent diverse directions of research and study within Natural Computing. I would like to ask them the question: "*Quo Vadis?*" (Where are you going?) Unlike in the Scriptural origin of this question, this is not a call to return to Rome. It is a request for sharing with the audience panelists' vision of the direction and future of Natural Computing. This is a question about their motivation to pursue this path of inquiry. Finally, the panelists may choose to reflect on the more general question of the future not just of Natural Computing but Computing in general.

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CONTRIBUTED PAPERS IN THE ALPHABETIC ORDER OF FIRST AUTHORS:

Evolution of functionality as the emergence of logical structures

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During evolution, in order to survive, living systems gradually develop a useful approximation of their environment. During that process, organisms have to perceive environmental properties and either incorporate them into existing functional traits or create entirely novel functional combinations.

Here, we create an agent-based system where agents can evolve an internal frame of reference against which they can functionally distinguish environmental properties. Basic elements of the frame of reference are segregation (ability to distinguish environmental objects) and categorization (ability to develop a variety of functional responses to an observed environmental object). Both segregation and categorization parameters are not predefined. Instead, they are defined during the evolutionary process as a function of their contribution towards the agent's survival. Therefore, the evolutionary development of the frame of reference is not externally guided but is driven by the internal emergence of systemic functionality. As a result, an arbitrary property of the environment becomes either (i) a proper signal that triggers a set of adaptive actions; (ii) a functionally unimportant background signal that is ignored.

In the model, the frame of reference of each agent is implemented as a growing complex network with randomly added nodes. Nodes are elementary functions (move, observe, transform …) while links between them indicate pair ordering, with an assigned probability of execution. The behaviour of agents is governed by the network structure. At each time step, the network topology can change in two fundamental ways: (i) a randomly chosen node is either added or removed to/from a random location in the network and (ii) new random links can be added to a network or existing random links can be removed. With such rewiring, we simulate the evolution of embodied cognition. The behaviour of agents on each time step is determined by traversing through their internal networks. If a node has multiple links, the order of path execution in a certain time step is determined according to the probability of execution. Each agent can develop multiple internal networks. Agents compete for limited resources and their evolution is governed by natural selection. Over time, selection strongly favours the emergence of networks that build a proper frame of reference by first identifying environmental signals and then execute a set of adaptive actions.

As a next step, we analyze logical structures that appear and grow during the evolution by transforming growing random complex networks into graphs that represent formal logic. An arbitrary directed graph does not necessarily hold all the properties of formal logic. Therefore, we first determine necessary axioms (e.g. axiom of pairing, the composition of logical connectives, the emergence of transitive law). Then, we analyze temporal (composition of functions by ordered pairs) and spatial (representation by non-ordered pairs) logical properties. We finally discuss the parallel generation of functionality and logical structures with spatial and temporal aspects.

Validation and correction of information by computing automata

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Learning is an important category of information acquisition. Machine learning utilizes automata for learning in general and language learning in particular. In addition, abstract automata are used for modeling learning by people. In this work, analyzing how people learn natural languages, we develop a new approach to modeling and performing language learning by abstract automata. This allows treating natural language learning as natural computing.

The conventional models of natural language acquisition assumes that in the process of learning, children, as well as adult learners, find out and memorize the correct words, rules of generating sentences, and rules of their utilization. However, this picture misses an important peculiarity of the learning process. Namely, people also gain knowledge of incorrect words and sentences and this knowledge helps not to use incorrect linguistic constructions in communication.

To model this process, we introduce a new type of computational automata called selective machines. A selective machine can not only generate (compute) words and texts but also eliminate (uncompute) words and texts. This property allows achieving higher power and lower complexity in computations.

A *selective machine* M has positive and negative processors which accept/recognize words.

The difference between positive and negative processors is their purpose of computation. Positive processors accept or recognize tentative (or possible) elements of a language. However, it is not assumed that all of them are correct (belong to the language under construction). The goal of negative processors is to recognize those elements that do not belong to the language under construction, that is, are incorrect. This allows building a language by the procedure where at first, tentative (or possible) elements of the language are extracted and then the incorrect words are eliminated.

We remind that a language L is accepted or recognized by a conventional automaton (machine) M, such as a finite automaton or a Turing machine, if this automaton accepts all words from L and only these words. It is denoted by L_M or $L(M)$ and is also called that language of the machine M.

In the case of selective machines, we have two types of languages.

The *positive language* $L(M_P)$ of a selective machines M is the language accepted/recognized by all positive processors of M.

The negative language is defined in a similar way.

The *negative language* $L(M_N)$ of a selective machines M is the language rejected/eliminated/prohibited by any of the negative processors of M.

Positive and negative languages together recognize the language of selective machines in the following way.

The language $L(M) = L(M_P) \setminus L(M_N)$ is the *language of the selective machine* M.

Taking two classes **K** and **H** of automata (algorithms), we denote by **K/H** the class of all selective machines, in which the positive processors are automata from **K** and the negative processors are automata from **H**.

We remind that the recognizing linguistic power RL(A) (RL($\boldsymbol{Q}$)) of an automaton A (a class $\boldsymbol{Q}$ of automata) is the class of all formal languages recognized by the automaton A (by the automata from the class $\boldsymbol{Q}$).

The goal of this work is to study the recognizing linguistic power of different classes of selective machines, for example, such as **FA/TM** or **TM/TM**, and compare their powers with the recognizing linguistic power of different classes of the basic classes of conventional recognizing automata, such as the class **FA** of all finite automata with a given alphabet, class **TM** of all Turing machines or class **ITM** of all inductive Turing machines.

It is possible to ask the question why the same automaton cannot generate words and exclude those that do not belong to the language under construction. The answer is yes it is possible but the results proved by the authors demonstrate that in many important cases, two automata – one positive and another negative, which belong to the same class K (for example, both are Turing machines) can generate, describe and recognize much more languages than one automaton from this class K (one Turing machine) can do.

To conclude, it is necessary to remark that before this approach to learning was studied in the context of formal grammars (Burgin, 2005; Carlucci, et al, 2009; Case and Jain, 2011). Here we explore learning as a natural information acquisition process modeling it with computing automata.

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Tag Systems and their Spatial Dynamics with Cellular Automata

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In 1920, Emil L. Post had developed a string rewriting logistic computational model that is a simple form of the normal canonical Post machine, this machine receives a string read the first symbol, deletes a constant number (defined by a deletion number P) of symbols at the be- ginning and appends, according to the symbol found at the beginning of the string, a string of symbols at the end (called production rule), this happens until there is not a sufficient number of symbols to delete or it is reached by halt symbol. Tag systems has applications on pure mathematics, logic, computation and, in recent proposals, physics. Cellular automata have been used for discrete modelling of dynamic and complex systems, their parallel computing capacity and the simplicity that make them as a functional and efficient tool. Also, cellular automata are able to express formal language into their evolution space. Both tag systems and cellular automata have been used to simulate universal Turing machines. This way, we research the production of strings from a tag system as a dynamical system evolution and show some particular cellular automata rules simulating specifically some tag systems. We discuss about how cellular automata can be used as a tool in tag systems evolution, by using the rules that we found and some tag systems. We also discuss the theory and computational model of parallel evolution of a tag system based on cellular automata. The basic idea of this analysis is based on the action of dynamics, which is relevant to the conceptualisation of the evolution of the overall system. A cellular automaton can be characterised by its evolution. The characterisation of the entire system depends on its behaviour. So, the tag systems that we simulated can be characterised on the spatial behaviour of the equivalent cellular automata.

Advancing human understanding with deep learning Go AI engines

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Improvement is a central issue for all serious players of pure skill board games. Which book to read? Which master to listen to? How to practice? Questions like this are often asked in the process of getting better. For Go players, the appearance of deep learning AI engines suddenly opened up new learning possibilities as they encode superhuman level playing skills, albeit in a black-box format. How can we improve our understanding of the game of Go by using the deep learning neural network AI engines? The research focus is shifting from creating more powerful AIs to enabling human players at all levels to benefit the technological advances. We start from the fact that the human mind has a better cognitive architecture. We have explanations, reasoning, the ability to form hypotheses and test them. In contrast, the AIs (AlphaGo and subsequent open-source implementations) are purely associative structures, mapping board positions to estimated results and good moves. From this perspective, it is somewhat ironic that a narrow AI advanced beyond the only AGI currently in existence, the human intelligence.

Arguably, this happened several times before, but this situation is more interesting than the case of the calculator (with superhuman calculating skills) since we do not do arithmetic by intuition.

There are two different approaches for using AIs as tools for learning about the game. We can try to open the black box of the neural network or embrace its opaque nature.

1. **Internal analysis of the neural networks - intelligible intelligence:** Unlike in the brain, we have complete access to the whole neural network, down to single neurons. We can try to uncover the abstract hierarchical representation of Go knowledge inside the network by using feature visualization. However, we know that neural networks may or may not have comprehensible representations. The space of possible Go-playing neural networks may have a vanishingly small fraction in human accessible formats.
2. **Improve our learning methods:** Learning at a professional level proceeds from intuitive understanding to explicit verbalizations. In the case of Go, strategic plans are explanations for what is happening on the board. Therefore, the methods of scientific knowledge creation do apply here. The AIs are inexhaustible sources of experiments providing high-quality statistical data. Growing Go knowledge can be faster by formulating plans when choosing moves rather than just looking up the best move recommended by the AIs.

We focus on the second case and we will review the existing practices of working with AIs in the Go community and study how a more deliberate application of scientific principles can enhance the human learning process.

Three Models of Gellular Automata

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We summarize our work on gellular automata, which are cellular automata we intend to implement with gel materials. If cellular automata are implemented as materials, it will become possible to realize smart materials having abilities such as self-organization, pattern formation, and self-repair. Furthermore, it may be possible to make a material that can learn from its environment. In this talk, we present three models of gellular automata, among which the third one is new.

Suppose such a smart material implements an artificial blood vessel. In that case, the vessel will be autonomously formed at an appropriate place in the living body, and it will recognize its deformation or occlusion and self-repair. Furthermore, it is possible to envision smart materials that learn appropriate functions by external stimuli.

The first model of gellular automata is based on gel walls separating cells of solutions. The gel walls are assumed to have holes that open and close by the surrounding solutions. We showed the Turing computability of the model by encoding rotary elements in the model.

The second model is much simpler than the first one and more suitable for implementation with gels. Gel walls also separate cells of solutions, but communication between cells is realized by diffusion of signal molecules as actually implemented by Murata and his colleagues. In addition to the Turing computability, we focus on self-stability in relation to the ability of self-repair.

We finally report our recent attempt in the third model to design gellular automata that learn Boolean circuits from input-output examples. In the model, supervised learning is realized as a kind of pattern formation. If smart materials gain such an ability, they can learn from their external environment. A cell is placed at each lattice point of a three-dimensional space. Each cell has therefore six neighbors. Some cells are specified as input nodes or output nodes. Other cells are either active or inactive. If a cell is active, it works as an OR gate. Boolean circuits are constructed in the three-dimensional cellular space. With Boolean values at input nodes, expected Boolean values at output nodes are specified as teacher signals. In other words, an example for supervised learning consists of given values at input nodes and expected values at output nodes. With each example, cells make state transitions and form a Boolean circuit consisting of OR gates between input and output nodes.

On sustainable self-explanatory executable document

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In recent years, we have been looking for a framework that can support our daily personal tasks, even in the presence of cognitive decline or fluctuations due to dementia or higher brain dysfunction. Our documents are usually not just static, but including executable documents with associated scripts. In order to ensure their readability as well as executability, careful choice of its supporting programming language and how to keep daily records are important issues.

The condition for an "ideal" sustainable self-explanatory executable document is:

1. I can understand and execute the documentation.
2. If 1 is impossible, \[Exists] x, I can show the document to others and ask x to help me understand and execute it.
3. If 1 and 2 are impossible, \[ForAll] x, x can understand and execute the document independently of me.

These are very important settings. We have to assume that we will not only have forgotten the documents we wrote, but not be able to process them in future. However it seems quite difficult to achieve because:

1. If your age is x years old, you need to expect the documents to be executed after 90-x years.
2. Your cognitive level will not remain the same for the period of time.

Over the past 50 years, many file formats for executable documents have been proposed, but most of them have been lost and only a few remain readable and executable to this day. This problem becomes more difficult because of the complexity of privacy issues related to personal documents.

In this study, we discuss the historical background and potential applications of self-explanatory executable documents. Our goal seems hopelessly difficult to achieve, but we need to present the best possible solution. However, since a general discussion is impossible, I will only describe my personal measures to achieve this goal.

The Paradigm of Natural Intelligence

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It will be argued that intelligence is a universal phenomenon present in all forms of life. It requires a new form of relationship with the environment, implying not only openness to energy flows but to information flows as well. External information processing, coupled with internal information processing, may produce an adaptive life cycle that manifests ('natural') intelligence, produces meaning, and realizes fitness value. Out from the basic prokaryotic conformation, the fundamental unit of natural intelligence, this phenomenon will develop hierarchically, via multicellularity, and particularly with the evolution of animal nervous systems. Then, natural intelligence will fully develop up to the point, in the human case, of exhibiting pieces of artificial intelligence that mimic some of the basic properties of the former—but they should not be confused. In contemporary societies, the essential link between intelligence and life has to be plainly revealed as a counterpoint to the link between artificial intelligence and computation.

1. THE CELL AS THE BASIC UNIT OF INTELLIGENCE

It is argued that without a proper understanding of natural intelligence, the scientific foundations of artificial intelligence will be shaky--notwithstanding the technological grandeur it is effectively achieving. Information processing is at the heart of natural or biological intelligence, but it is very different from the way it is organized in artificial systems (Marijuán et al., 2015; Slijpevic, 2018). The living cell provides an alternative paradigm, a new conceptual panorama, where information flows, signaling systems, gene transcription and protein synthesis are contemplated as a coherent unit. It is the adaptive life cycle, which can manifest intelligence, can communicate and produce meaning, and finally is capable of evolving. In an artificial system we would be talking about perception, memory, learning, anticipation, decision-making, etc., all of them carried by means of computations. But the 'mechanics' of natural intelligence is utterly different.

2. THE PROKARIOTIC LIFE CYCLE

We see the life cycle of cellular sytems (the simplest ones, prokaryotes) as a trivial characteristic of life, but actually it is the most amazing information design any engineer could think of. The living cell is a system that self-constructs out from environmental stuff according to an inner blueprint that is separated from the constructive system itself (echoing von Neumann self-reproducing automata). In the distributed constructing system of multiple ribosome nanomachines we find a complex conjunction of informational architectures supported by inner 'computational protein networks' capable of sending their signals across distant functional areas. This vast constructive process distributed across the cell system only needs some transient copies of mRNAs and the raw basic materials. Reproduction will follow. With unencumbered repetition of the reproduction cycles, there is a tendency to excess, to fill in the ecological niche; but the emerging trophic interactions will put all participants "in their place." Further, *systemic variations* affecting the blueprint will appear, becoming phenotype changes and implying *differential survival*; thus evolution occurs… and quite many evolutionary 'vehicles' will be assembled in multicellular organisms for the adaptive exploration of the new complexity scenarios, implying both DNA blueprint and interactive behavior in the coupled environment (Wagner, 2019).

3. FROM EUKARYOTIC CELLS TO MULTICELLULAR ORGANISMS

The different kind of intelligence that eukaryotic cells evolve with respect to prokaryotic cells has been discussed thoroughly in (Marijuán et al., 2010, 2013). In some sense, the further complexity growth we see in multicellular organisms is a *déjà vu* of the prokaryotic phenomenology. In another sense, the uncanny complexity of signaling and transcriptional processes in all the eukaryotic kingdoms of life challenges the meaningfulness of whatever simplified scheme we may propose. Nevertheless, there are a few evolutionary guidelines on the fundamentals of the 'new eukaryotic order': symbiosis, signaling expansion, cell-cycle modularity, and ontogenetic multicellular development.

The further evolution of intelligence in Nature has kept pace with the progressive complexification and sophistication of the nested information flows that subtend and involve all the different realms of life (Wurtz, 2021). From the signaling pathways of unicellular prokaryotes to the signaling systems of multicellular eukaryotes, and to the central nervous systems of vertebrates, advanced mammals and anthropoids—organized not only in ecosystem networks but also in close-knit societies. This evolutionary capability to arrange complex organisms and complex organizations behaving sophisticatedly in an open-ended environment has represented the definite emergence of the phenomenon of intelligence in Nature and at the social level.

4. FROM HUMAN INTELLIGENCE TO SOCIAL INTELLIGENCE

Seemingly the linguistic capability of humans has put our societies in an entirely new path. That's right, but we can also analyze the evolution of the information flows and the processing structures in our societies along some of the previous guidelines: both the natural information flows related to the individual lives and the artificial flows generated via technological systems. Like in the case of cells or in nervous systems, a degree of "social intelligence" might also be ascertained regarding the combined working of social entities and institutions.

In human societies, the new thinking derived from natural intelligence and information science should contribute to a more cogent social management of the whole system of sciences. The art of "knowledge recombination" has to be practiced with some more scientific guidance, so that the immense body of scientific knowledge accumulated –in the order of 6,000 disciplines– becomes useful to reorient the productive system and to grant collective sustainability. A new scientific culture has to be promoted; a new dialog among theoretical and experimental scientists and philosophers from very different fields has to be established; and the natural phenomenology underlying the essential link between intelligence and life has to be plainly revealed as a counterpoint to the link between artificial intelligence and computation. In the extent to which this can be achieved, an important social mission will be fulfilled.

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Composing reversible computers in a reversible and conservative environment

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Reversibility is one of the fundamental physical laws of nature. We study the problem of how we can construct reversible Turing machines (RTMs) in an environment that obeys a reversible and conservative microscopic law. Here, we use the framework of an elementary triangular partitioned cellular automaton (ETPCA) as a spatiotemporal model of the environment. In an ETPCA, configurations evolve according to an extremely simple local transition function, and hence it is suited for investigating how simple computationally universal reversible CAs can be.

Thus, the problem is to find an effective construction pathway that starts from a local transition function of an ETPCA, and leads to RTMs.

In our previous research, it was shown that RTMs can be constructed systematically in a reversible and non-conservative ETPCA 0347, where 0347 is an ID number in the class of 256 ETPCAs [2,3].

Here, we solve this problem in a reversible and conservative ETPCA 0157. In [1], a Fredkin gate, which is a universal reversible logic gate, can be realized in the cellular space of ETPCA 0157. Hence, RTMs are, in principle, realizable in this cellular space. However, if we use reversible logic gates the resulting circuit becomes very complex, since two or more signals must arrive at exactly the same time at each gate. Here, we use a reversible logic element with memory (RLEM), rather than a reversible gate, as a logical primitive. By this, the whole circuit is greatly simplified.

Here, several conceptual levels are appropriately introduced on the construction pathway, and hence the problem is decomposed into several sub-problems. These sub-problems are the following:

(1) Finding useful patterns and phenomena in ETPCA 0157,

(2) making an RLEM by utilizing these phenomena,

(3) composing functional modules for RTMs out of RLEMs, and

(4) constructing RTMs by assembling these functional modules.

By these steps, RTMs are constructed systematically and hierarchically even from

a very simple local transition function.

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Learning Computing from Nature: Reflection on the Klein Four-Group

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Qualification of computing as natural can be interpreted in many essentially different ways. It will be understood here as the functioning of models of the information transformation acquired through abstraction from similar processes in natural phenomena occurring without any engagement of the human purpose oriented action. In a slightly oversimplified form, natural computing is one which is discovered while artificial is invented. Turing Machine could qualify as natural computing device (human computers observed by Turing did not have any idea about the purpose of their work), but its special version of the Universal Turing Machine as artificial (it was not derived from an observation of a natural process and it was designed with the specific purpose of the simulation of all other Turing Machines). Another example of natural computing can be identified in the Artificial Neural Networks derived from the observation of natural neural systems. Certainly, better name would have been Abstract Neural Networks, but this is not our concern.

The subject of this study is the quest for new and essentially different forms of natural computing. The central question is about the promising directions for exploration of natural phenomena in which new paradigms of computing could be found. An example of success in designing innovative computing can be the model of quantum computing. However, someone can question how much conceptually innovative it is (quantum phenomena where involved in the technological progress of computing devices from the very beginning) and quantum computing clearly belongs to what here is understood as artificial computing (result of the attempts to overcome the limits of speed in standard computing).

The most likely domain of natural phenomena involving really innovative forms of information processing is life with its extremely high level of complexity and efficiency. The main assumption of this study is that the two aspects of natural information processing deserve closer inspection: the capacity of information integration and the complex hierarchic architecture of information processing reflecting the complexity of the organization of life.

The interest in both these aspects is not entirely new. Integration of information became one of key concepts in the search for scientific explanation of phenomenal consciousness. Hierarchic architecture of neural networks is the basis for deep learning. However, in both cases there is no fundamental theoretical formulation of the idea of integration or hierarchy. Integration is identified with statistical patterns of observed simultaneous activations of neurons in terms of mutual entropy, while layers of neurons in the network with directional convergence of connections are the only hierarchic configuration considered. There is no description of the mechanism of integration or analysis of the influence of the possible alternative forms of hierarchies.

I provided in my earlier publications mathematical model of information integration (including the description of integrating gates) and of the hierarchic architecture of computing. The former is based on the conclusions from the algebraic characterization of the degree in which a system is classical or quantum type (degree of the product irreducibility of its underlying logic). Here, I will focus on only one aspect of hierarchic organization of computing: the transition between different levels of structural complexity. The study can be summarized as an attempt to answer the question: What is the role of the humble Klein Four-Group?

Natural Computing Systems with Tactile Sense

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We construct a natural computing system based on the sense of touch. The natural computing system we construct does not depend on the conventional category of computer science. The computing consists of a computing entity and an algorithm. We define an algorithm as "a list of instructions for solving a problem" and a computing system as "the act or process of calculating an answer or amount by using an algorithm".

Interactions can be divided into two types: the actor and the target of the action are clear or not. For example, in the interaction by e-mail, the actor and the target are clear. On the other hand, in daily conversation, non-verbal interactions such as facial expressions and behaviours are added to verbal interactions. Therefore, the actor and the object of action cannot be separated. The change in the other person caused by one's speech changes one's speech and facial expressions. In other words, by acting on the other person, we receive an action from the other person.

We define this kind of ambivalent action as tactile interaction. The sense of touch is ambivalent; we can block the action of sight by closing our eyes, while we cannot close our sense of touch as we close our eyes.

Tactile interactions are common in nature. For example, molecular and cellular interactions are tactile interactions; when a vaccine is administered to the immune system, the immune system remembers the molecules to attack. However, neither the immune system nor the target molecule is auditory. Molecular recognitions rely on tactile of the shape of molecules. In viruses, macromolecules called glycans act as molecular "tags", and proteins and glycans "touch" the cell surface to search for the most stable contact position.

We define a tactile computing system as a system in which an algorithm designs the interaction. For example, the system of the immune system and viruses is a tactile computing system. The way the sugar molecules are arranged, i.e. the algorithm, mediates the interaction. The virus changes the arrangement of sugar molecules to escape the immune system's attack and becomes a so-called mutant. We define programming as the modification of the algorithm according to the purpose.

We have proposed Tactile Score, TS, a notation that describes the Spatio-temporal pattern of tactile interaction. In TS, a staff notation with the third line representing the average interaction force, the lower line representing the strong interaction force, and the upper line representing the weak interaction force. The duration of the interaction force is described using musical notes. For example, if a quarter note is one second, an interaction force of a certain magnitude lasting for two seconds is described by a half note.

We have been using the Tactile score to convert various natural systems into computing systems. Recently, we have been applying tactile computing systems to the treatment of dementia. There are very few effective treatments for dementia, such as Alzheimer's disease and Parkinson's disease, and the primary treatment is medical-drug therapy. We are conducting clinical research on haptic interaction to treat dementia. We have used direct tactile stimulations and indirect tactile stimulations by ultra-low frequency (Deep Micro Vibrotactile, DMV, we invented) in clinical research with Advanced Research Center for Geriatric and Gerontology, Akita University (prof. Hidetaka Ota) [2]. A preliminary clinical study showed that both methods improved cognitive function; these clinical studies indicate that this method is also effective for depression and insomnia. We are currently searching for more effective algorithms. Our tactile computing system has been successfully applied not only to dementia but also to medical treatment of the elderly (prevention of frailty) and beauty care.

Natural computing with tactile sense has only just begun. We have accumulated much knowledge in computer science, molecular computing and molecular robotics. We aim to develop research on natural tactile computing systems by making the best use of them.

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References

[1] Yasuhiro Suzuki and Rieko Suzuki, Tactile Score, A Knowledge Media for Tactile Sense, Springer Verlag, 2014.

[2] Kodama A, Suzuki Y, Kume Y, Ota H (2021) Examination of the effect of Deep Micro Vibrotactile stimulation on cognitive function for elderly with Alzheimer's Disease. Ann Alzheimers Dement Care 5(1): 001-003. DOI: 10.17352/aadc.000016.

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TENTATIVE SCHEDULE OF PRESENTATIONS AND PANEL DISCUSSION OF 13th INTERNATIONAL WORKSHOP ON NATURAL COMPUTING (IWNC)

FRIDAY, September 17, 4:00-12:30 UTC

<u>PLENARY SESSION FOR THE SUMMIT (4:00-7:00 UTC)</u>

INVITED SPEAKERS

4:00-5:00 UTC: Genaro J. Mart´ınez – "Machines computing and learning?"
5:00-6:00 UTC: Andy Adamatzky – "Computing with slime mould, plants, liquid marbles and fungi"

6:00-7:00 UTC: Panel Discussion "Natural Question about Natural Computing"

<u>IWNC CONFERENCE SESSION (7:30-12:30)</u>

(Only names of presenters without co-authors are displayed)

7:30 – 8:00 UTC: Yasuhiro Suzuki – "Natural Computing Systems with Tactile Sense"
8:00 – 8:30 UTC: Pedro Marijuan – "The Paradigm of Natural Intelligence"

8:30 – 9:00 UTC: Katsunobu Imai – "On sustainable self-explanatory executable document"

9:00 – 9:30 UTC: Attila Egri-Nagi – "Advancing human understanding with deep learning Go AI engines"

9:30 – 10:00 UTC: Igor Balaz – "Evolution of functionality as the emergence of logical structures"

10:00 – 10:30 UTC: Marcin J. Schroeder – "Learning Computing from Nature: Reflection on the Klein Four-Group"

10:30 – 11:00 UTC: Kenichi Morita – "Composing reversible computers in a reversible and conservative environment"

11:00 – 11:30 UTC: Masami Hagiya – "Three Models of Gellular Automata"

11:30 – 12:00 UTC: Alan B. Cerna-González – "Tag Systems and their Spatial Dynamics with Cellular Automata"

12:00 – 12:30 UTC: Mark Burgin – "Validation and correction of information by computing automata"