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The Conceptual Premises for the Construction of an Oscillation-Based Social Simulation Paradigm

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Abstract. This multidisciplinary research introduces the conceptual premises and major guiding principles for the construction of an oscillation-based multi-agent simulation paradigm (OSIMAS), where complex social agents are understood as information processes virtually represented as systems of oscillations. Consequently, the social systems composed of such agents assume the form of multivariate information processes virtually represented as a pervasive information field (PIF). It is shown that the PIF model may serve as a simulation medium for contextual information storage, specifically targeting uncoupled and indirect interactions among social agents capable of affecting and perceiving broadcasted contextual information. In this way, the PIF approach is expressive enough to represent contextual broadcasted information in a form locally accessible and immediately usable by network agents.

Keywords: pervasive information field, complex social systems, multi-agent systems.

1. Introduction

In light of growing social tensions, crises, and complexity, there is rising concern about the validity of our traditional understanding of the fundamental processes which take place first in people's minds and then in society and the whole ecosystem as well. Whatever our research domain, we see increasing fragmentation and complexity in terms of the models and methods applied, while how different research domains and levels work and fit together remains much less explored.

This multidisciplinary paper presents some research results for the "common denominator" across various complexity levels. It takes the form of universal assumptions and principles described under the OSIMAS[1] (oscillation-based multi-agent system) paradigm. The OSIMAS paradigm employs a conceptual trinity of models[2] [1]: PIF (pervasive information field or, in other words, virtual oscillatory field), OAM (oscillating agent model), and WIM (wave-like interaction mechanism). This paper focuses on the introduction of the PIF model.

It is beyond the purview of this article to provide a comprehensive review of the surge in publications on field-based coordination and communication paradigms. In short, a review of the literature showed other similar approaches in many research directions, such as vibrating potential fields [2], quantum computation as a model of consciousness [3], the formation of Bose-Einstein condensate for the production of most organized light waves (i.e. biophotons) in living tissues [4], intra- and intercellular communication

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1 The OSIMAS project is funded by the European Social Fund under the Global Grant measure; project No. VP1-3.1-SMM-07-K-01-137, see http://osimas.vva.lt/. The OSIMAS cross-disciplinary paradigm integrates computational intelligence, social science, and complexity science in order to achieve its goals. In other words, we are developing a fundamentally novel simulation paradigm for multilevel complex systems, which integrates universal principles of self-organization and synchronization in oscillatory networks observed in physical, biological, and social domains.

2 The proposed unique social systems modeling paradigm escapes some theoretical assumptions applied to traditional economic systems. It frees us from the need to describe the working theoretical model of the system under research "from top to bottom" and forces us to create adequate empirical frames within which the modeled economic systems would be able to realize the self-organization mechanisms from "bottom to top." Here, the "bottom" denotes not simply intelligent agents, but, rather, self-organized information processes immersed in a pervasive information field.

mechanisms [5], the CEMI theory of consciousness [6], the neurophysics of consciousness [7], field computations in natural and artificial intelligence [8], field-based coordination mechanisms for multi-agent systems in the robotics domain [9], organic computing for the emergent behavior of complex systems [10], amorphous or pervasive computing in contextual environments [11], etc.

In sum, a review of multidisciplinary literature suggests that there are no separate laws for the large (biological, sociological, or cosmological scale) and the physics of the small (atomic/subatomic scale), but rather universal, all-embracing laws for self-organized, multifaceted information, which permeates all living and nonliving states of energy-matter [12].

A review of related research projects throughout the world shows many other international groups, such as the EU FET flagship project FuturICT initiative[3], the Self-Organizing Systems Research Group of Harvard University in Cambridge (USA), the Pervasive Artificial Intelligence (PAI) Research Group of the University of Fribourg (Switzerland), the Centre for Computational Analysis of Social and Organizational Systems (CASOS) of Carnegie Mellon University, etc. An entire group of related projects is also being implemented under the EU research umbrella called FET (Future and Emerging Technologies) under the ICT program of information and communication technologies in the FP7 (Seventh Framework Program)[4].

The great diversity among theoretical approaches indicates that there is not yet one single widely accepted theory of field-based communication and coordination. Notwithstanding this apparent diversity of approaches, there are some universal scale-free principles that are valid across various field-like coordination approaches. In the following sections, we systemized those basic principles and adapted them for the field-like simulation approach in the social domain.

For instance, there are some studies using neurophysiological approaches which lead to unified field models of consciousness [6, 7]. They give an impetus to elaborate on the idea of unified field models for collective mind-fields of coherently convergent (congruent) human groups. In this way, information societies (the macro world) can no longer be viewed as separate from the quantum effects taking place in the conscious mind-fields of the members of a society. Indeed, societies can be understood as global processes emerging from the collective behavior of the conscious and subconscious mind-fields of the individual members of a society. In this way, emergent social processes are produced by a collective mind-field and inherit some degree of coherent (synchronized) field-like behavior[5].

2. OSIMAS Assumptions

First of all, let us emphasize that, when formulating postulates, we are looking for universalities across different spatial scales and time horizons. In essence, we are searching for pervasive fundamental laws of self-organizing information unconstrained by space and time. If, for instance, some field-like fundamental principles work in the quantum world and in cellular biophysics, we must admit that the same principles are in one way or another expressed in the mesoscopic world of social systems, too. However, the form and expression of these fundamental principles vary across different scales.

Second, when formulating basic assumptions and postulates, we want to elaborate how field-based underlying reality can be applied in modeling pervasive contextual environments in complex information-rich social networks. In other words, we formulate foundations for modeling emergent and self-organizing features of modern information-rich social networks, where not only intangible but also tangible natural resources and even social agents themselves can be simulated as oscillating processes immersed in an all-pervasive contextual PIF. Hence, the basic assumptions and postulates of the OSIMAS paradigm:

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[3] In fact, the OSIMAS paradigm is targeted to create one of the prototypes for the Living Earth Simulator instrument under the FuturICT flagship project.

[4] FET-proactive initiatives carry some projects closely related to the field-like and self-organized approaches, which deal with complex, autonomic, adaptive, brain and neuro-bio inspired multi-level systems, e.g. FOCAS, QICT, PERADA, APF, initiative Awareness (projects RECOGNITION, SAPERE, ASCENS, EPICS).

[5] Following the latest findings in the neurosciences [3, 5, 7], we hypothesize that self-organization and coherent behavior in social systems is not so much correlated with the particular patterns of agents' actions, but with the synchrony of their activity. A core motif of social behavioral synchrony could be the convergence of the otherwise dissipating and self-destructive activity patterns of the individual members of a society.

1st Postulate. Social systems can be modeled as complex informational processes comprised of half-autonomous interdependent organizational layers, e.g. individual, group, and society. Information is coded and spread globally almost at the speed of light via broadcasting telecommunication networks. Modern information societies are like accumulated potential fields of various information where information is propagated not via peer-to-peer interactions between economic agents, but increasingly more like fields transmitted through broadcasting information channels (Internet, GSM, radio, TV, etc).

2nd Postulate. Like all complex systems, social systems are always on the verge of inward (inner organization) and outward (behavioral) chaos. They are constantly balancing between order and disorder. Therefore, social systems have the naturally inherited property of changing and adapting while searching for niches to survive in. Hence, the main feature of social systems is not the capacity to stay in inward and outward states of equilibrium (which are constantly changing), but rather the capacity to change and adapt while searching for inward and outward equilibrium.

3rd Postulate. Uncoupled and indirect interactions among social agents require the capability of affecting and perceiving broadcasted contextual information. Therefore, a social information network can be modeled as a virtual oscillatory field (PIF), where each network node receives pervasive (broadcasted) information field values. Such a model provides the appropriate means to enforce indirect and uncoupled (contextual) interactions among agents. It is expressive enough to represent contextual broadcasted information in a form locally accessible and immediately usable by network agents.

4th Postulate. The simulation results of social systems behavior do not reflect observable reality unless the simulated models acquire the features of living systems, e.g. adaptability, self-organization, field-like inner coordination, and outer communication.

5th Postulate. The individual members of a society can be modeled as information-storing, -processing, and -communicating agents in an information network society. In a deeper sense, information societies operate through agents, which are complex multifaceted self-organized information processes composed of mind-fields of quantum field-like processes originating in brains.

6th Postulate. Agents, as complex multifaceted field-like information processes, can be modeled by adapting the physical analogy of multifaceted field-like energy, which is commonly expressed via spectra of oscillations. In this way, an agent becomes represented in terms of a unique composition of oscillations or an individual spectrum.

7th Postulate. An agent's inner states can be represented in terms of organized multifaceted information which expresses itself in the form of a preserved specific energy set. The latter is realized via a specific spectrum of oscillations. The distribution of an agent's oscillations over an individual spectrum, in contrast to a random distribution, carries information about the agent's self-organizational features, i.e. negentropy (order). Hence, social agents are complex processes that dynamically change multifaceted inner information-energy states depending on their (i) experience, (ii) behavioral strategies, and (iii) received information from a PIF.

8th Postulate. Artificial societies can be modeled as superimposed sets of individual spectra or, in other words, as a PIF. Social order emerges as a coherent superposition of the individual spectra (self-organizing information processes). Hence, social order can be modeled as coherent fields of information resulting from the superposition of the individual mind-fields of the members of a society.

9th Postulate. Social order, i.e. self-organized and coherent behavior in social systems, is not so much correlated with the particular patterns of agents' actions, but with the synchrony of their activity. That multi-agent synchrony is achieved via simultaneous (in the same phase) resonance. Synchronicity is involved in the social-binding problem – how information distributed among many agents generates community. The social-binding process can be envisaged as a global resonance state.

10th Postulate. We assume that the primal spontaneous emergence of self-organized information has dealt with self-sustainment in the first place and later with self-propagation. Therefore, these processes are preprogrammed in all self-organizing systems as fundamental laws for increasing local negentropy (order, information). Hence, the core reason for the emergence of social synchrony is related to the fundamental property of all self-organized systems, i.e. the preservation or increase of negentropy, which creates socially organized behavior (accordingly directing the system's resources).

In sum, all agents can be integrated into a common PIF spectrum as individual sets of oscillation bands, which are memorized and managed by the oscillating agent model (OAM). This latter model realizes the production rules for the transformation of inward energy (a set of active oscillations), which can be defined *a priori* or induced from the agent's behavioral strategy [1]. In our proposed paradigm, agents can communicate the information they possess according to their behavioral strategy. Communication takes place via a common medium, i.e. a PIF, but it is managed by the wave-like communication mechanism (WIM). The next section briefly outlines the OSIMAS paradigm setup and specifically the PIF model.

3. PIF: Conceptual Scope

In fact, engineers are starting to understand that, to construct self-organizing and adaptive systems, it may be more appropriate to focus on the engineering of proper interaction mechanisms for the components of the system rather than on the engineering of their overall system architecture [9]. One obvious example can be seen in modern telecommunication networks, where peer-to-peer connection protocols are no longer prevalent. This happens mainly because they are not efficient enough for multitasking, parallel processing, congested traffic control, conflict resolution, etc. Hence, not accidentally, there is a striking structural similarity between modern telecommunications and social networks. As a matter of fact, the main information traffic in social networks takes place through telecommunications networks, which act as the backbone of the modern network-based information economy.

The information era has, in fact, shaped efficient protocols for complex information traffic in telecommunication networks, where (i) each agent can instantly send and receive information simultaneously through multiple communications channels, (ii) information flows are locally managed by the agent's preferences as if having the ability to "tune" to different broadcasting channels, and (iii) agents have become the processing, storing, and retransmitting nodes in social networks. Information is spreading through a multitude of multimedia networks with the speed of light. After all, it does seem that we are immersed in emanating fields of virtual information [1].

In essence, the PIF model serves as a means for information (and associated energy) storage, dynamic distribution, and organization. According to the OSIMAS paradigm, pervasive information is distributed in fields, and fields – although expressing some global information – are locally perceived by agents, who are inseparable from their PIF. In this way, the PIF simulates universal media, which contain all the possible multifaceted self-organizing information present in a real system.

Hence, multifaceted information is modeled in the form of an all-embracing virtual field, which can be realized as a programmable abstraction where all tangible and intangible observables are represented as a set of oscillations (energy equivalents). In other words, everything that exists in such a system is represented via spectra of oscillations. Consequently, a PIF is a grand total of all individual spectra. The PIF model is constructed following these principles:

- Social systems constitute yet another layer of self-organizing information, where mainly the same scale-free and field-like universal laws apply.
- Social systems behave in a coherent way because they are integral holistic units, where each part is inseparable from all the rest. Each part is a sum of the influences of all the other parts. Likewise, each part directly or indirectly influences all the other parts.
- Such systems should not be fragmented to their independent parts, i.e. separate agents as such. Therefore, we should simulate agents as local processes of self-organized information in a global all-embracing multifaceted information field (PIF).
- In the PIF, dimensionless self-organizing information processes, i.e. agents, can be modeled by using such abstractions as sets of standing waves or, in other words, resonant frequencies. An agent has as many resonant frequencies as it has degrees of freedom. At resonant frequencies the agent stores energy, i.e. self-organized information. This information is used to enhance inner processes and outward behavioral patterns.

- A homeostatic agent can be represented in terms of the local energy spectral density (LESD) distribution, which describes how the inner energy (or its variance in time series) is distributed with frequency. Meanwhile, the system-wide distribution of LESD provides the global energy spectral density (GESD) distribution, which uniquely describes the state of the PIF at each moment.
- The main way for the agent to increase negentropy (negative entropy or information) is via adoption of some set of resonant frequencies, which may yield to beneficial behavioral patterns in a dynamic environment. The adoption of new resonant frequencies (information) changes the agent's LESD and GESD distributions accordingly.
- Homeostatic agents, i.e. self-organized information processes, are self-programmed and usually proactive. They search for ways to sustain and increase self-organized information via the increase of inner negentropy. There are many ways to reach the same level of negentropy by employing different LESD distributions.
- In general, information is represented by the levels of synchronization (and of coherence) locally within an agent and globally within agent populations. Deviations from random oscillations constitute local and global negentropy, or self-organizing information. Local field potentials reflect the degree of synchronization among agents.
- Coordination between agents can be realized via coherent convergence, i.e. synchronization of oscillation phases. Large-scale integration or "social binding" involves synchronous oscillations of local field potentials. The coherent convergence of resonant oscillations leads to synchronization among self-organized information processes (agents).
- Synchronization as a process locally invokes searching for beneficial information and globally means minimizing a system's entropy. In that sense, both local and global processes are homeostatic and self-organized to maintain or increase negentropy.

PIF computation is a theoretical model of information processing operations that take place in natural systems. A PIF can be treated mathematically as a multifaceted function Ψ over a bounded spatial set Ω. The value of the function Ψ is restricted to some bounded subset of real numbers $\Psi: \Omega \rightarrow K$ for a K-valued field. Thus, for the time-varying field we have $\Psi(k, t)$, where $k \in K$.

In general, we require that Ψ for each moment and space location be uniformly continuous, square-integrable, finite-energy, Hilbert space[6] functions [8]. In fact, we are interested in the continuous dynamics of local and nonlocal interactions of pervasive information fields. Hence, dynamic changes can be defined by field transformations and differential equations. The linear transformation of fields can be described by using integral operators of the Hilbert-Schmidt type as continuous mapping functions, which map one or more input fields Ψ into one or more output fields $\Phi = K\Psi$ for K-valued fields over Ω. In the presence of multiple stimuli, we can use multilinear integral operators. Such mapping represents a superposition of all the stimuli.

It is important to note not only that we should care about the superposition of field frequencies and magnitudes but also that phases are very important, too. Phases play a significant role in the synchronization phenomena of self-oscillatory and excitable systems [8]. According to one phase synchronization theory of chaotic systems, dynamic coherent behavior emerges as a consequence of nonlinear synchronization in complex networks [13]. Therefore, fields can be treated as complex valued.

In fact, coherent MAS (multi-agent systems) can be identified from the JTFR[7] as time-persistent distributions of synchronous oscillations. The process of self-organization increases negentropy in the form of distribution of resonant frequencies in the otherwise uniformly distributed oscillations field. The main characteristic for chaotic systems to behave as phase-synchronized is the existence of characteristic rhythms which allow one to observe and investigate coherent behavior [13]. In the frames of such a phase and frequency approach, it is quite natural that synchronization processes in various systems of different nature will have close similarities and can be studied by using common field-based tools.

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[6] Hilbert spaces are widely used as models of continuous knowledge representation, but not all elements of Hilbert space are physically realizable.

[7] In fact, joint time-frequency representation (JTFR) provides a bridge between time and frequency representations by visualizing some spectral and temporal information simultaneously. JTFR depicts how information-energy states (represented by frequency distributions) change over time. JTFRs are useful for the representation and analysis of dynamic LESD and GEST containing multiple time-varying frequencies.

4. Conclusions and Discussion

This article provides universal scale-free and field-like principles valid across self-organized complex systems of different nature. On the basis of these principles, we have formulated a set of fundamental postulates, which form an OSIMAS paradigm, i.e. a novel way for the understanding and simulation of self-organized complex social processes. According to the OSIMAS paradigm, societies can be understood as global processes emerging from the collective coherent behavior of the conscious and subconscious mind-fields of the individual members of a society. In this way, emergent social processes are produced by a collective mind-field and inherit some degree of coherent (synchronized) field-like behavior.

In short, this research introduces the novel idea of multifaceted field-like media for pervasive information storage and communication, i.e. the pervasive information field (PIF) concept. We argue that the PIF approach is beneficial for the simulation of the collective mind-fields of coherently convergent (congruent) human groups.

We propose joint time-frequency representation as a means for the visualization and analysis of local agent-based and global PIF energy distribution states. This proposed field-like approach (PIF concept) is expressive enough to represent contextual broadcasted information in a form locally accessible and immediately usable by network agents.

Like all pioneering approaches, this study needs thorough further investigation. This work, however, gives some clear outlines and their explanatory sources for further exploration of the OSIMAS paradigm and the PIF model in particular.

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