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Interdisciplinary Principles of Field-Like Coordination in the Case of Self-Organized Social Systems[1]

D. Plikynas, S. Masteika, A. Budrionis

***Abstract*—**This interdisciplinary research aims to distinguish universal scale-free and field-like fundamental principles of self-organization observable across many disciplines like computer science, neuroscience, microbiology, social science, etc. Based on these universal principles we provide basic premises and postulates for designing holistic social simulation models. We also introduce pervasive information field (PIF) concept, which serves as a simulation media for contextual information storage, dynamic distribution and organization in social complex networks. PIF concept specifically is targeted for field-like uncoupled and indirect interactions among social agents capable of affecting and perceiving broadcasted contextual information. Proposed approach is expressive enough to represent contextual broadcasted information in a form locally accessible and immediately usable by network agents. This paper gives some prospective vision how system's resources (tangible and intangible) could be simulated as oscillating processes immersed in the all pervasive information field.

***Keywords*—**field-based coordination, multi-agent systems, information-rich social networks, pervasive information field

I. Introduction

DUE to the remarkable advances in a broad spectrum of technologies and topics the field of pervasive computing and communications has been witnessing increased attention among many researches and application developers. There are, though, some obvious concerns about our rudimentary understanding of the underlying fundamental processes which take place in the social domain, where these computing and communication technologies finally subside. Wider understanding of the social self-organizing processes may help to envisage further technological developments and trends in the field.

Hence, this paper draws attention to the underlying social processes from the holistic systems view. In the simplest sense, it introduces an idea of a multifaceted field-like media for pervasive information storage and communication, i.e. pervasive information field (PIF) concept.

In fact, PIF can also be referred as a virtual oscillatory field employed as simulation media 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 [1]. In this way, PIF serves as a basic cornerstone in the proposed oscillations based multi-agent system (OSIMAS) simulation paradigm. According to the OSIMAS paradigm, all social information processes can be simulated as self-organizing, dimensionless and field-like entities[2].

The proposed paradigm does not start from the "ground zero", as literature review gave striking similarities with some other approaches in many research directions like vibrating potential field [2], quantum computation as a model of consciousness [3], formation of Bose-Einstein condensate for production of most organized light waves (i.e. biophotons) in the living tissues [4], intra and inter cellular communication mechanisms [5], 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 robotics domain [9], organic computing for emergent behavior of complex systems [10], amorphous or pervasive computing in contextual environments [11], etc.

Review of the related research across the world shows many other international groups like Self-organizing systems research group from Harvard University in Cambridge (USA), Pervasive artificial intelligence (PAI) research group from University of Fribourg (Switzerland); Center for computational analysis of social and organizational systems (CASOS) from Carnegie Mellon University, etc. A whole bunch of related projects are also implemented under EU research umbrella called FET (future and emerging technologies) under the ICT program of information and communication technologies in the FP7 (seventh framework program)[3].

It is beyond the purview of this article to provide a

D.P. Author is with the Research Center at the Academy of Business&Management, Lithuania (e-mail: darius.plikynas@gmail.com).
S.M. Author is with the Research Center at the Academy of Business&Management, Lithuania (e-mail: saulius.masteika@vukhf.lt)
A.B. Author is with the Research Center at the Academy of Business&Management and Vilnius University Mathematics and Informatics |Department, Lithuania (e-mail: andrius@vva.lt).
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[2] OSIMAS paradigm employs the conceptual trinity of models [1]: PIF (pervasive information field or in other words virtual oscillatory field), OAM (oscillating agent model) and WIM (wave-like interaction mechanism).
[3] FET-proactive initiatives carry some projects closely related to the field-like and self- organized approaches, which are dealing 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).

comprehensive review of the surge of publications on the field-based coordination and communication paradigms. In sum, a multidisciplinary literature review suggests that there are not separate laws of large (biological, sociological or cosmological scale) and the physics of the small (atomic/subatomic scale), but rather universal all embracing laws of self-organized multifaceted information, which permeates all living and nonliving states of energy-matter [12].

The great diversity among theoretical approaches indicates that there is not yet one single widely-accepted theory of field-based communication and coordination. Notwithstanding apparent diversity of approaches, there are some universal scale-free principles 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 from the neurophysiological approaches, which lead to the unified field models of consciousness [6,7]. It gives an impetus to elaborate on the idea of the unified field models of collective mind-fields of the coherently convergent (congruent) human groups. In this way, information societies (macro world) no longer can be viewed as separate from the quantum effects taking place in the conscious mind-fields of society members. Indeed, societies can be understood as global processes emerging from the collective behavior of conscious and subconscious mind-fields of individual society members. In this way, emergent social processes are produced by a collective mind-field and inherit some degree of coherent (synchronized) field-like behavior.

Following 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 synchrony of their activity[4]. A core motif of social behavioral synchrony could be convergence of otherwise dissipating and self-destructive activity patterns of individual society members.

In fact, this hypothesis is very important in the OSIMAS paradigm as it offers a different worldview, which opens new perspectives for modeling and simulating emergent social properties as collective mind-field effects. Based on this hypothesis, we are designing collective mind-field model, which potentially could simulate some complex social cognitive and behavioral phenomena [1].

II. Basic Principles and Assumptions

In this section, we briefly summarize systemized universal principles of self-organization in social and other complex systems and integrate our findings into one coherent set of postulates, which lays ground for the OSIMAS (oscillations based multi-agent system) simulation paradigm. For the sake of clarity let us recall that proposed OSIMAS paradigm employs the conceptual trinity of models: PIF (pervasive information field), OAM (oscillating agent model) and WIM (wave-like interaction mechanism). This trinity of models stands as the cornerstone upon which all ideas are build in the paradigm, see Fig. 1.

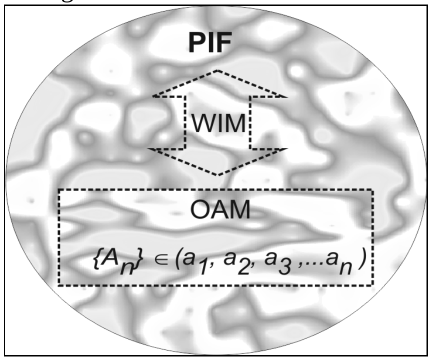

Fig. 1 Three major OSIMAS models: (i) all embracing pervasive information field (PIF), (ii) oscillating agent model (OAM), which identifies each agent from a set {An} in the PIF and (iii) wave-like interaction mechanism (WIM), which realizes interactions between those agents.

First of all let us emphasize, that while formulating postulates, we are looking for universalities across different spatial scales and time horizons. In essence, we are searching for the pervasive fundamental laws of self-organizing information not bounded by space and time constraints. If, for instance, some field-like fundamental principles are working in the quantum world and in the cellular biophysics, we admit that the same principles are in one or another way expressed in the mesoscopic world of social systems too. However, the form and expression of these fundamental principles across different scales varies. Only the most fundamental (attributeless, dimensionless and timeless) underlying principles remain the same.

Second, while formulating basic assumptions and postulates, we want to elaborate how field-based underlying reality could be applied for 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 could be simulated as oscillating processes immersed in the all pervasive contextual PIF. Hence, here follow the basic assumptions and postulates of the OSIMAS paradigm:

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

[4] Regime of collective behavior is one of the basic coherent states of globally synchronized agents. The basic phenomenon of these structure formations is synchronization, which is universal in many dynamical systems and can be understood from the analysis of common models of oscillatory networks [13].

through the broadcasting information channels (Internet, GSM, radio, TV, etc).

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

3 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 gives 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.

4 Postulate. Simulation results of social systems behavior are not adequate to the observable reality, unless, simulated models acquire features of living systems, e.g. adaptability, self-organization, field-like inner coordination and outer communication.

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

6 Postulate. Agents, as complex multifaceted field-like information processes, can be modeled, adapting the physical analogy of the 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 individual spectrum.

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

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

9 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 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 amongst many agents generates community. The social binding process can be envisaged as a global resonance state.

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

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

III. Conceptual Design Of Pervasive Information Field (PIF)

The major question we address in this study: what is the natural and most efficient way of simulating complex information networking and interaction mechanisms in order to reflect the observed multiplicity of modern broadcasting telecommunication systems used by social agents? 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 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. In fact, the main information traffic in social networks flows through telecommunications networks, which act as a backbone of the modern network-based information economy.

In fact, the information era has shaped efficient protocols for complex information traffic in the 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, (iii) agents became processing, storing and retransmitting nodes in the social networks. Information is spreading through a multitude of multimedia networks with the speed of light. After all, it does seem like we are immersed in emanating fields of virtual information [1].

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

Hence, multifaceted information is modeled in a form of 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, all that is in such a system is represented via spectra of oscillations. Consequently, PIF is a grand total of all individual spectra. PIF model is constructed following these principles:

1. Social systems constitute yet another layer of self-organizing information, where principally the same scale-free and field-like universal laws apply.
2. 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 summa summarum of the influence of all the other parts. Likewise each part directly or indirectly influences all the other parts.
3. Such systems should not be fragmented to the independent parts, i.e. separate agents as such. Therefore, we should simulate agents as local processes of self-organized information in the global all embracing multifaceted information field (PIF).
4. In the PIF, dimensionless self-organizing information processes, i.e. agents can be modeled using such abstractions like 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 agent stores energy, i.e. self-organized information. This information is used to enhance inner processes and outward behavioral patterns.
5. 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, system-wide distribution of LESD gives global energy spectral density (GESD) distribution, which uniquely describes the state of PIF for each moment.
6. 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 the beneficial behavioral patterns in the dynamic environment. Adoption of the new resonant frequencies (information) changes agent's LESD and GESD distributions accordingly.
7. Homeostatic agents, i.e. self-organized information processes, are self-programmed and usually proactive. They are searching how to sustain and increase self-organized information via increase of inner negentropy. There are many ways to reach the same level of negentropy employing different LESD distributions.
8. In general, information is represented by the levels of synchronization (and of coherence) locally within an agent and globally within agents' populations. Deviations from random oscillations constitute local and global negentropy or self-organizing information. Local field potentials reflect the degree of synchronization among the agents.
9. 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. Coherent convergence of resonant oscillations leads to the synchronization among self-organized information processes (agents).
10. Synchronization as a process locally invokes searching for the beneficial information and globally means minimizing 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. 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 $\Psi:\Omega\to K$ *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 are uniformly continuous, square-integrable, finite energy, Hilbert space[5] functions [8]. In fact, we are interested in the continuous dynamics of local and nonlocal interactions of pervasive information fields. Hence, dynamical changes can be defined by fields' transformations and differential equations. Fields' linear transformation can be described using integral operators of 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

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

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

Based on the proposed framework, the following question arises – how to visualize the entire PIF model in a single yet comprehensive manner. In fact, joint time-frequency representation (JTFR) provides a bridge between time and frequency representations, visualizing some spectral and temporal information simultaneously, see pseudospectra illustration in Fig. 2. 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.

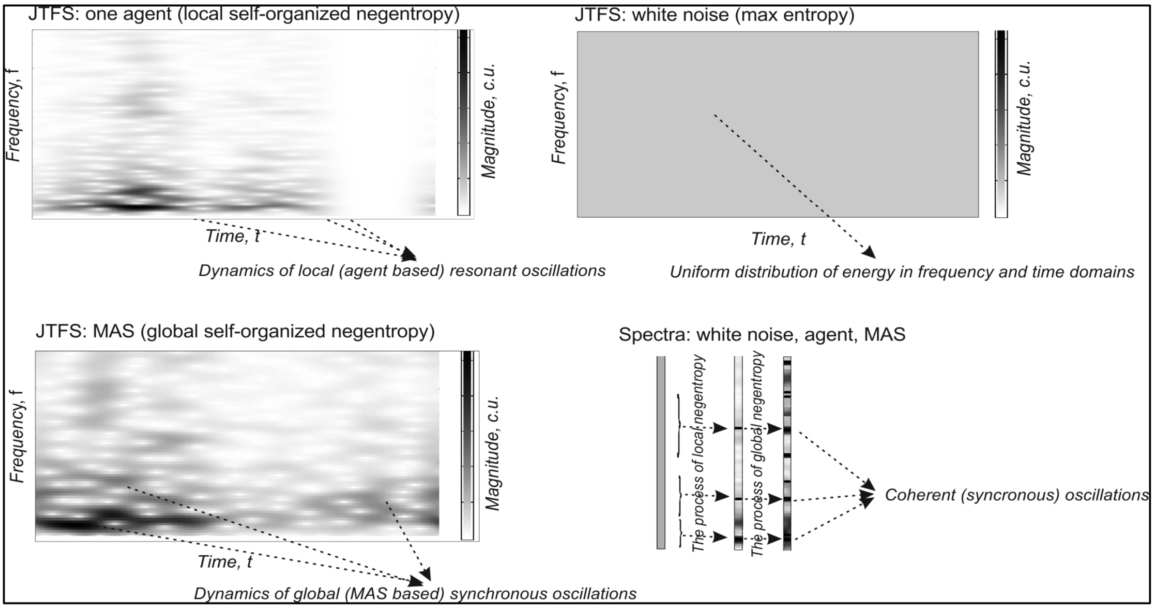

Fig. 1 Pseudospectra diagrams used for illustration of the joint time-frequency power spectra (JTFR) approach as a mean for visualization and analysis of local agent-based and global PIF energy states containing distributions of multiple time-varying frequencies. In the top right diagram, white noise oscillations are uniformly distributed (with maximum entropy). In the top left diagram, LESD exhibits ordered structure of oscillations depending on agent's behavioral patterns and inner states. In the down left diagram, GEST exhibits overall superposition of LESD, i.e. PIF representation.

In fact, coherent MAS (multi-agent systems) can be identified from the JTFR as time persistent distributions of synchronous oscillations. The process of self-organization increases negentropy in a form of distribution of resonant frequencies in the otherwise uniformly distributed oscillations field (see the right down diagram in Fig. 2). The main characteristic for chaotic systems to behave phase synchronized is the existence of characteristic rhythms which allow to observe and to investigate coherent behavior [13]. In the frames of such 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.

IV. Conclusions And Discussion

We have formulated a set of fundamental postulates, which form OSIMAS paradigm, i.e. a novel way for the understanding and simulation of self-organized complex social processes. Specifically, we introduced an idea of a multifaceted field-like media for pervasive information storage and communication, i.e. pervasive information field (PIF) concept. We argue that PIF approach is beneficial for the simulation of collective mind-fields of the coherently convergent (congruent) human groups.

According to OSIMAS, societies can be understood as global processes emerging from the collective coherent behavior of conscious and subconscious mind-fields of individual society members. In this way, emergent social processes are produced by a collective mind-field and inherit some degree of coherent (synchronized) field-like behavior. 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.

This paper gives some prospective vision how system's resources (tangible and intangible) could be simulated as oscillating processes immersed in the all pervasive information field. It provides fundamental premises for designing pervasive information simulation models, which are employing scale-free universal principles of field-like coordination.

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

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