NANOPOLIS: an infrastructure for communication in the nanotech world

Dan BOG [*+] and Florin CIONTU [**]

[*]iMediasoft Group, Grenoble, FRANCE, dan.bog@imediasoft.net
[+]Politehnica University of Bucharest, ROMANIA,
[**]TIMA Labs, Grenoble, FRANCE, florin.ciontu@imag.fr

ABSTRACT

In this paper we present the fundamental concepts that led to the development of Nanopolis as a Distributed Knowledge Network for Nanoscale Science and Engineering. We start with a syncretic picture composed of ideas that have gained momentum in the past decades of cybernetic and sociological research. This approach is destined to provide a formal framework for the co-evolution (self-consistent evolution) of the semantics of communication and the structure of its underlying support. Based on this concept, the link to the more practical sphere of day-to-day actions is made by the fundamental thesis of Nanopolis: a part of the systemic challenges of nanotechnology can be translated into problems related to the need for spontaneous emergence of new communication networks. Finally, we present the current ongoing initiatives of Nanopolis and outline the envisioned future developments.

Keywords: nanotechnology, distributed knowledge network communication, multi-agent systems

1 INTRODUCTION

We are currently starting to foresee the morphing of nanotechnology from a futuristic prediction into the technology of tomorrow. A case for this statement is made by plans for moving the manufacturing of nanostructures from lab to fab and the applications from paper to prototypes. But in the light of the new opportunities we also start foreseeing the transformative effect brought by the drift towards the real-world – we are inevitably entering a phase where the dynamic of nanotech is not dominated anymore by what's happening in a couple of dozens of labs but by the complex dynamic of the research –industry – government triple helix. Research groups are starting to focus on specific details instead of dreaming of opening new paths, industrialists and research groups are entangling their activities more and more and not in the least voices asking for regulatory policies begin to be heard. At this stage we are entitled to take a systemic view of nanotechnology's development and address problems specific to the general dynamic of social systems like those related to the communication networks structuring such systems.

The Nanopolis project (www.nanopolis.net) takes such an approach by focusing on mitigating the impact of some of the challenges characteristic to nanotechnology through the stimulation of new communication patterns between the players in the nanotech world. Under its current manifestation, the project is a distributed knowledge network aiming at transposing today's knowledge on matter exploration at the atomic scale into a virtual representation space. More than 200 research groups are participating in this project coordinated by iMediasoft.

In this paper we present the fundamental ideas lying at the foundation of Nanopolis, its current stage as well as future actions. At first sight, the ideas presented here are abstract and grounded in theoretical developments, but they assemble into a formal framework implemented through a series of real-life actions as shown in the second part of the paper.

The remainder of the paper is structured as follows. In Section 2 we present the ideas on communication in knowledge based systems that sustain the fundamental framework of Nanopolis. The transposition of these ideas into the current actions of the project is presented in Section 3 together with an overview on future actions. We finally end with conclusions in Section 4.

2 FORMAL FRAMEWORK

Communication and the structure of its underlying support co-evolve interdependently driven by the wave of self-organization characterizing social systems and more generally the biosphere. This Section summarizes some ideas supporting this statement and sketches a framework for the development of Nanopolis as a distributed knowledge network.

We proceed with the construction of this framework in two phases:

- At first we take into account self-organization as a general phenomenon in social systems or ecosystems and the role of self-organization in determining the multi-layered structure of these systems.
- These general considerations can be particularized for the case where communication is seen as a semantic layer of a social system

2.1 Self-Organization in Social Systems

Self-organization and entropy decrease have been acknowledged to various degrees as intrinsic characteristics of social systems although their relation with *ab initio* mechanisms at the origin of living systems is still controversial. The former mechanisms have been studied by Ilya Prigogine[1] and his school in a Nobel prize awarded work on entropy decrease in non-equilibrium chemistry. Non-equilibrium systems can export entropy thus evolving to a higher level of order. At critical bifurcation points these systems can either fold back into chaos or evolve to more and more differentiated states. Irrespective of the existence of a link between these molecular level phenomena and the upper levels of the biosphere, Prigogine's work is significant in that it provides a model for a self-organizing system. Moreover, the concepts of entropy and information are rather cybernetic than physical. They can be applied to any system for which the basic assumptions of thermodynamics related to non-differentiability of basic elements hold. As such, Axelrod's model [2] on dissemination of culture is a good example of integrating the concept of order in its entropic sense into the study of social phenomena. The subject is further detailed in [3] through an analysis of the influence of the structure of social networks on the non-equilibrium order-disorder transitions. Finally, self-organization has been tackled in a generic manner in the context of Multi-agent Systems [4] and a sociologic view focused on self-organization in the knowledge society is provided in Ref. [5].

The structure of self-organizing systems is intimately related to the concept of hierarchy. This is unsurprising considering the direct correspondence between hierarchy and entropy reduction. More subtle arguments could also play a role, like the stability of hierarchical systems with respect to fluctuations. The latter concept is allegorically expressed in Simon's parable on Tempus and Hora, the two watch makers [6]. However, purely hierarchical structure can lead to a suboptimal degree of global self-organization of the entire system. In other words, a purely egoistic strategy for an organism can easily lead to a non-optimal result for the species. Thus, hierarchical organization and its variations have been rejected as realistic models for self-organizing systems [7].

This led to the adoption of heterarchies as a more appropriate model for the study of complex multi-level structured systems. As mentioned in [8], heterarchies are structures with "no single governing level", where "various levels exert a determinate influence on each other in some particular respect". Co-evolution is the process describing this kind of self-consistent evolution of a multiple-level structure. The concept has a significant practical value as, beyond theoretical conceptualizations, its existence has been confirmed in various instances like the co-evolution of eukaryotic viruses and their host organisms [9], the study of the interaction of different HIV populations[10] or the relationship between communication networks and social structures[11] which is the focus of this paper.

The conclusion up to this point is that self-organization is a ubiquitous principle governing the dynamics of a broad range of systems with a strong social component. Moreover, heterarchy is it currently considered the most appropriate model for such systems due to its appropriateness for taking into account the self-consistent evolution on multiple levels in multi-layer structures.

2.2 Communication as a semantic layer

Two ideas will be developed in the next paragraph: (1) how communication can be integrated as a semantic layer within a heterarchy and (2) how communication co-evolves with the other layers of this heterarchy. For communication to be seen as a layer of semantic nature in a heterarchic model of a social system one must derive communication as a partial projection of one of the other layers of the system. Partial projection denominates the operation allowing derivation of a new abstract layer from an existing one through aggregation of elementary agents and interactions. This derivation process is represented in Figure 1.

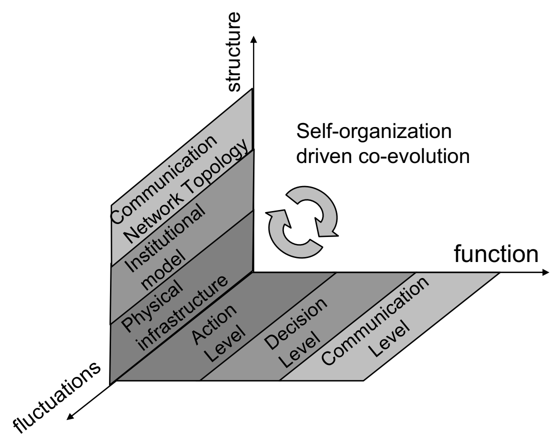

Figure1. Communication as a partial projection of the decision level in a heterarchy-based representation of the social system

We adopted the function/structure/fluctuation interdependency as defined in [1] in order to be able to distinguish between the co-evolution of function and structure and the co-evolution of layers obtained from successive projections. The fundamental level of an agent-based representation of a social system is structured through analogy with a real-world infrastructure. A first projection allows us to derive the *decision level* by associating to event the corresponding decision at the origin of any action. Furthermore, the correspondence between decision and communication is obtained by selecting three classes of information:

- Communication channels constitute ***the co unication network to ology*** and are essential to convey information to an agent. Different attributes can be attached to a communication channel.

- *Perception* is essentially a matter of integration within a previously existing referential. How this referential is shaped, can be a matter depending on other communication actions. A fundamental problem of communication is whether they conveyed message has all the attributes allowing it to be integrated into an existing structure.

- *Analysis* is considered a process of almost mechanical nature corresponding to applying a set of operators to a data structure. The set of operators is considered common knowledge to all the agents in a population. The fundamental distinction between perception and analysis is that the former is dependent on the current state of an agent while the latter is considered dependent on knowledge transmissible independently of the individual experience of the agent.

Once communication can be projected as a layer of a heterarchic structure, its co-evolution can be characterized in the multi-level multi-theoretical framework defined in Ref. [11] to study the emergence of new communication networks. The latter are defined in opposition to formal networks which are the ones most commonly defined by our social institutions. Two extreme examples are relevant for formal networks: bureaucracies which are totally hierarchic and "free markets" where every communication action is a kind of bargaining and which are completely anarchic. On the contrary, emergent networks are the ones with connections naturally arising in social networks. According to the same authors, the emergence of communication networks is the result of a complex interplay of basic mechanisms acting at different levels: a single actor, dyad, triad etc. The basic mechanisms can be grouped into several theoretical classes: relating to self-interest, mutual interest and collective action, contagion, cognition, exchange and dependency, homophily proximity etc. The co-evolution of communication and its underlying social substratum can be characterized through the superposition of these basic mechanisms and can be pointed out by observing a critical point in any communication revolution. Thus, after a new communication technology substitutes older ones and respectively enhances communication itself, at a critical point businesses restructure their organizations in order to take full advantage of the new medium(ex: Business models organized around the internet).

In conclusion, communication networks can be seen as a partial projection in a heterarchical structure. Their co-evolution with other components of the global structure can be characterized *ab initio* by taking into account the elementary mechanisms governing the emergence of communication networks.

3 NANOPOLIS: DISTRIBUTED KNOWLEDGE NETWORK

After the previous formal developments we now proceed to explaining the current action lines of Nanopolis. Central to this is the fundamental thesis of Nanopolis which tries to express some of the systemic challenges of nanotechnology in terms of problems related to the need for the emergence of new communications networks. After exemplifying this thesis with two case studies we present the current initiatives. The Section ends with a description of future actions and their envisioned impact.

3.1 Fundamental Thesis

The fundamental philosophy of Nanopolis must be understood by taking into account the emergence of communication networks in the context of new challenges and new opportunities brought in by nanotechnology.

Coping with a part of the systemic challenges specific to nanotechnology requires the activation of new emergent networks mechanisms.

Two examples can be used to illustrate this thesis: the challenge posed by interdisciplinarity and the unbalanced evolution of *the triple helix government-research institutions-industry.*

Interdisciplinarity is becoming the manifesto of all speeches on the challenges of nanotechnology. As mentioned in Section 2.2, decisions to pursue a path are always conditioned by the available communication channels, and the global understanding of the chain of concepts within each topic is integrated (perception and analysis). However, the topology of a communication network is determined of course by physical issues but also by the "distance" between the concepts mastered by individuals. This means that in order to stimulate communication between individuals with different backgrounds, one must counter the absence of proximity in their backgrounds. Once this is countered, and once different agents see a mutual interest, communication will become self-reinforcing. This is a clear case of conceptual distance preventing communication. It is also a case where the enhancement of cognitive mechanisms, would contribute considerably to the emergence of communication mechanisms between agents who don't benefit otherwise from conceptual proximity.

The second example is the unbalanced evolution of education and science. The traditional bureaucratic circuit where new major changes are made at best every 5-7 years is not good enough to keep with the fast pace of discovery. A student coming out of undergraduate school today and wanting to do research in nanotechnology has no means to make an informed choice and most of the time his decision is arbitrary. Lastly, nanotechnology will apparently have most of its impact in traditional fields of the economy where big players are already established but history shows that existing businesses fail to recognize the potential of new technologies.

3.2 Current Initiatives

In its current stage of development, Nanopolis is identifying the critical points in the systemic evolution of nanotechnology and constructing the basic mechanisms allowing the stimulation of the emergence of new communication patterns. The first component is constituted by ongoing sociological research. The second one is currently materialized by two components:

- a software infrastructure allowing the participants in Nanopolis to supply/use knowledge in a distributed e-collaborative environment. Typical transactions supported by these systems are: (1) local processing of knowledge (2) multimedia transposition and the validation protocol and (3) content deployment.
- a considerable amount of scientific content related to matter exploration at the atomic scale, produced through the interactions of the institutions participating in the project. As this content is gathered in real-time, it is subsequently projected in different spheres of interest: industrialists, scientists or the general public. Information was presented via multimedia representations like 2D and 3D computer-generated images and animations.

The resulted informational content is disseminated as an interactive multimedia three-volume encyclopaedia series. The first two volumes are focused on the most frequently used tools for matter exploration at the atomic scale: synchrotron light and neutrons. The third volume is focused on nanotechnology.

"Exploring matter with synchrotron light", the 1st volume, has been developed in partnership with the "European Synchrotron Radiation Facility" and the help of APS (USA), Canadian Light Source, Soleil Synchrotron (Fra) and other synchrotron facilities. The CD-ROM has been awarded the prize for the best scientific multimedia – UNESCO Sept. 01, also recognized of pedagogical interest by the Ministry of Education of France.

The 2nd volume, "Exploring matter with neutrons", was developed in partnership with the Institutes Laue-Langevin (Fra), ISIS (UK), LANSCE (USA), Jülich Forshungszentrum (Ger), LLB-CEA (Fra), GKSS (Ger) and other members of the international neutronics community.

The 3rd volume of the Nanopolis series, "Exploring Nanotechnology" is currently under development and covers the research domains spawned by the emergence of new exploration techniques in the last few years. A first edition is expected to be released in 2004.

In addition to the these 3 tomes encyclopaedia series , Nanopolis is now evolving into a Virtual Communication Pole on the Internet offering precious resources of today's knowledge of the most recent physics, methods and technologies at the atomic scale in direct connection with the head R&D figures from all over the world.

3.3 Future initiatives

Future initiatives will focus on two classes of players: universities and policy-concerned institutes. The iMediaLearn system of iMediasoft will allow universities to integrate the multimedia content available on Nanopolis into their educational curriculum. Policy-concerned institutes, governmental as well as non-governmental will be involved in the project thus clearly mirroring the dynamics of the triple helix research-industry-government and further creating new communication bridges within the nanotech world.

4 CONCLUSIONS

Essential to this paper was our initial observation that nanotechnology reaches a point where its evolution is determined by the complex social factors and at this point we can apply systemic considerations. Our theoretical developments in this direction target to formalize the relationship between communication and the rest of the factors determining the dynamic of the field. The purpose of this approach is the automatic mirroring of this dynamic into Nanopolis as a distributed knowledge network. Furthermore, stimulating elementary mechanisms within this network should generate new self-sustaining patterns of communication. In the end, the emergence of these new communication patterns should provide a solution to some of the systemic challenges of nanotechnology.

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