RESEARCH STATEMENT

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Background and Motivation

Scientific progress is inconceivable without powerful computation and the Internet today. Recent efforts in autonomic computing and communications are focused in developing systems which automatically adjust their behaviour in response to the changing conditions of their work environments. The goal of this research involving the whole range of contemporary computer science from automata theory to artificial intelligence, is to manage the growing complexity of modern computing and communications architectures and enrich them with capabilities that occur in living systems such as self-configuration, self-optimization, self-repair and self-protection. On the other hand, life and physical sciences always demand high-performance computation for their advancement. Therefore, recent research roadmaps both in computational systems biology and autonomic systems are targeting to perpetuate and enrich the knowledge, technology and methodology transfer between analytic life sciences and synthetic engineering sciences. However, I dare to question the firmness of the bridge between converging sciences and claim that it is impossible to make any significant progress in this multidisciplinary field of research without inaugurating a breakthrough paradigm change towards *biologically driven mathematics and computation*.

My driving argument is that living systems have fundamentally different notions for self-organization from those conceived in engineering sciences today. Whereas artefacts are designed and programmed to serve human needs as tools and mechanisms, organisms are just beings with the only purpose to maintain, survive and reproduce in a changing environment. The former are closed deterministic systems conform to the laws of physics; the latter are open non-deterministic systems [1] that also follow the patterns of biology. Therefore, when devising the plan for future converging sciences, one should be aware of the limits of engineering and of the fact that "various relations within organisms…are outside the scope of metric mathematical biology" [2] and contemporary science. This holds also for computer science (dominated by the Turing machine model for the past 30 years) and for the emerging discipline of *nature-inspired* or *natural computation* [3], including constructivist approaches such as evolutionary, neural and neuromorphic, as well as cellular/membrane and molecular/DNA computation. They all still suffer the inertness of exclusively syntactic and "mechanistic computing models…by utilizing numerical computation algorithms which are based on *recursive* functions" [4].

Scope and Purpose

I am broadly interested in the research of distributed self-organising and self-assembling (autopoietic) communication architectures such as those i) for wireless ecology remote sensing, ii) for scalability and adaptation to highly dynamic situations in ultra-complex environments, as well as iii) for peer-to-peer interactions between autonomous computing elements and in how such designs shape and evolve into multidimensional hybrid, i.e. both natural and artificial, social and eco-systems. In this context, I regard the emerging disciplines of *autonomic computing and communications* (self-reconfiguration, self-optimization, self-healing, self-protection, self-adaptation, self-awareness) and *biomolecular, nano-computing/ nano-communications and size/time-dependent phenomena*[1] backed by previous research in cybernetics, molecular biology and neuroscience as well as computational electronics, programmable networking and artificial intelligence as fundamentals for these studies.

I have developed a long-term research program in an interdisciplinary area, which I refer to as *Integral Biomathics* [5]. In my doctoral thesis [6], I defined the Wandering Logic Intelligence (WLI) framework which was implemented as system architecture [7, 8] and robust ad hoc mobile routing [9] and P2P resource discovery algorithms [10] for large scale distributed systems of virtually unlimited size. My plan is to continue the elaboration, the study and the development of this work at my host institution in the context of Integral Biomathics from both system-theoretic and engineering point of view with the goal to devise system architectures for future generations of synthetic biophysical automata.

[1] in particular, the new concepts, mechanisms and methods in quantum electronics for exploiting the capabilities of molecular and biomolecular structures and nanoscale materials to construct novel components and devices out of biopolymers, carbon nanotubes and nanomagnets into nanosensors, cellular automata and nanoelectromechanical systems.

Approach and Objectives

I propose a research program as an integral part of the emerging discipline of natural or nature-inspired computation. My investigation addresses the phenomena of emergence, adaptive dynamics and evolution of self-organizing, self-maintaining, self-replicating and self-healing computational systems and communication architectures in a profoundly new way. In this context, I regard living systems as morphogenetic fields manifested as structural-functional patterns by means of autopoietic networks. This process involves *'hidden'* relational semantics which dynamically enfolds and unfolds inside the constituent elements as a result of the composite interplay with each other and their environments. The attained knowledge can be then used in biosynthetic system design which goes beyond Turing's discrete computation model and von Neumann's self-replicating automata, thus unleashing science to grow towards new horizons.

The goal of this work is the implementation of this model within an adequate engineering frame of relevance, rather than development of imitations or replicas via arbitrary selection and emulation of a set of limited 'organic' features. This will be achieved by means of: (i) investigating the biological imperatives for computation as seen in my vision of *integral biomathics*, and (ii) developing a prototype of naturalistic pervasive computing system based on a relational semantics model of neuronal morphogenesis.

The expected result is a naturalistic model of *neuronal system computation* which explains how synaptic plasticity develops in response to external stimuli. This process will be traced from the level of neuron group interactions through molecular biochemical reactions within single neurons down to the level of quantum coherence in tubulin nanostructures in terms of continuous and discrete biocomputation.

This project is intended to open the horizon and organize my own vision for a new field of interdisciplinary research: *Integral Biomathics.* I will benefit from the exchange and cooperation with first class research groups in computation and biology at my host institution which will offer me an adequate work environment. Beneficial for me will be also the intellectual feedback of the collaborating partners Prof. Bruce J. MacLennan (University of Tennessee, USA), Prof. Tatsuya Nomura (Ryukoku University, Japan), Prof. Leslie Smith, Evan Magill and Kenneth J. Turner (University of Stirling, UK).

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