Sorinel Adrian Oprisan

Statement of Research Accomplishments and Interests

My search for new paradigms is founded on in-depth physical principles' understanding and rigorous computational methodologies. I believe that involving students in my research projects and providing them with the opportunities to learn how to do independent research is the main method furthering academic progress both for my students and for myself.

My research interests are broad and include analytical methods for description of selforganizing systems, computational approaches on complex systems modeling based on cellular automata, chaos and nonlinear theory, neuromorphic modeling and implementation of biological circuitry, computational neuroscience, bioinformatics, data mining and artificial intelligence, theoretical condensed matter, and nonextensive statistics.

Present and Future Research

Starting from my previous and current research projects, there are several directions of research that I wish to pursue over the next years:

- Computational Neuroscience
- Complex Systems
- Chaos and Nonlinear Dynamics
- Nonequilibrium and Nonextensive Statistics
- Theoretical Condensed Matter
- Enhancement of Teaching through Technology

Computational neuroscience

One of the objectives of my research in computational neuroscience is to develop an analytical method for stability and phase control in coupled nonlinear oscillators. The envisioned application of my research is the central pattern generator (CPG), which is an autonomous unit capable of generating rhythmic and adaptive output without higher level inputs. The CPGs are

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Statement of Teaching Accomplishments and Interests

My teaching abilities come from a combination of previous teaching experience and a well formed knowledge base in a relatively large area of topics. Coupled with good communication skills and methods, as well as a caring attitude towards students, I am optimistic in my pursuit of a successful teaching career.

I see my previous teaching experience as shaped three different directions:

- formal preparation
- direct teaching
- study and research.

Formal preparation for teaching allowed me to get a well-organized and supervised instruction on teaching techniques, on presentation and examination tools. During my undergraduate studies, in parallel with my physics courses, I attended a 2-year course program that included classes on school psychology, pedagogy, and methods of teaching physics. Coupled with practical training as physics instructor (teaching intensive physics courses) for advanced high school students, this preparation allowed me to form the necessary pedagogical abilities. My experience was further enhanced through training and supervision at both the “Al. I. Cuza” University of Iasi, Romania and the University of New Orleans, U.S. I have participated in teaching enhancement sessions, incorporating simulated teaching, analysis of videotaped teaching, multicultural and diversity topics. I am continuously involved in initiatives that improve the quality of teaching. I also participate in workshops and conferences related to the increased use of technology in the classroom. Furthermore, one of my research interests is the efficient use of technology in teaching. These efforts have been distinguished by publishing three textbooks. The first is a conceptual and problem solving skills enhancement textbook for undergraduate level thermodynamics and statistical mechanics. The second is a laboratory manual for computational methods of theoretical physics accompanied by corresponding software package. Last but not least, a graduate level textbook disseminating the stochastic methods with particular emphasize on Fourier optics.

My teaching experience is vast and includes both graduate and undergraduate courses. From early 1990 until now, I have taught several courses on general physics, thermodynamics and statistical mechanics, quantum mechanics, electrodynamics, theoretical mechanics, computational physics (Pascal-based course), chaos and nonlinear theory, and selforganization principles of complex systems. My responsibilities involved the full design of class materials and examinations, teaching lectures, and labs, along with the holding of office hours, testing and grading. Throughout my career, I have received positive feedback from students and many of my undergraduate students decided to pursue graduate school. At the same time, I encouraged students to pursue their own research initiatives by suggesting topics and by assisting them in the development of such projects. Many of the papers I published in peer-reviewed journals (i.e. Physics Letters A, Chaos) were coauthored with some of my students. After 1999, I had the privilege to work with experienced faculty from both the psychology and physics departments at the University of New Orleans in helping them manage office hours, and aid with sessions, laboratories, grading, supervising graduate students, and the like. Their advice together with observing their teaching process helped me enrich my teaching experience. In addition to direct teaching, I was also involved in the development of web-based versions of the courses which I taught, designing session materials, online quizzes etc. I actively used the blackboard system to post course syllabus, class notes, homework assignments, solutions to problems, etc. I am also an enthusiastic user of the “WebAssign” system (http/:www.webassign.net) that allows me to select assignments, follow students’ progresses, and respond to students’ queries in a timely manner.

A condition for being a good teacher indicates a strong knowledge base. This is where the courses which I attended as well as the in depth study of several issues (thermodynamics and statistical mechanics, quantum physics, electrodynamics, chaos and nonlinear dynamics, selforganization and complex systems) are playing a vital role. In order to expand my knowledge base, after I got my doctorate degree in theoretical physics from “Al.I.Cuza” University of Iasi, Romania (1998), I accepted a postdoctoral position in computational neuroscience at the University of New Orleans. In parallel with my research, I studied and earned my graduate degree in computer science from the University of New Orleans focusing on in depth topics like programming languages, operating systems, image processing, pattern recognition and bioinformatics.

In general, my teaching style is a synthesis of methods that are dynamically employed based on the various courses topics and with the main focus on meeting the different learning styles of the student body. I see myself as a facilitator with the overall goal of developing in students the capacity for independent action, initiative and responsibility. I use the traditional lecture method supplemented by the active learning and discussion. I organize the class around the main ideas of the topic, prepared and presented using overhead transparencies. In addition, if and when the need for further explanations arises or practical examples are explored, I use the blackboard and “WebAssign” system.

The student body is characterized by a large variety of learning styles. To stimulate their interests and to encourage active learning from their part I challenge the students to discover new concepts as solutions to problems that are raised. This process is done through either direct questions, drama / role playing (where, for example, students are parts of a computer system interacting), or through critically analyzing the concepts presented. I found the method of peer instruction, introduced by Eric Mazur at Harvard University, extremely useful in teaching fundamental concepts of physics and I embraced it for the introductory physics classes I taught at the University of New Orleans. The “convince-your-neighbors” discussions not only reduce the monotony of a classically-taught introductory physics lecture, but also stimulate the students to think about the materials presented to them and significantly reduce the students’ frustration with the introductory physics courses. I also try very hard to encourage students to ask their own questions and to stop me whenever they feel the need for more in-depth clarifications. Through this constructivist approach, the students are able to reinforce the recently learned concepts. I also enthusiastically use an interactive classroom response system ("clicker") to asses the accuracy of concept understanding that instantly gives me a global view of what was well explained and understood, and what must be further developed with more examples and guidance. However, these methods might not always capture the full image of the class; therefore, I am also employing polling to get quick assessments on the level of understanding. In such an instance, I present a problem and ask the students whether they would chose one answer rather than the other. The outcome of this method is beneficial twofold. First, the students get a reinforcement on the topic discussed, and are also trained in decision taking and problem making. Second, for me, I have a quick way to asses the level of understanding for the entire class, and when a significant number gets a problem wrong, to go back and revisit the topic.

In addition to the traditional class time, I spend time maintaining an electronic resource repository. In physics courses, the use of computers for practical demonstrations is a must. This is why, for example, I use the Internet to search for online applications of the concepts I am teaching and provide the students with links to them. In class, I also provide a brief description and encourage students to find it out. Asking the students to provide their own findings for everybody’s benefit also emphasizes the active learning process here.

The assessment of the class plays an active part of the teaching process. Through homework exercises, practical assignments, and written examinations, I encourage students to better understand the topics at hand and develop creative and investigative skills. In my experience, the peer instruction method leads to a significant improvement in concept understanding without diminishing problem solving skills. In addition to the peer instruction method, I actively use recitation sessions to further develop some topics of interest and strengthen problem solving skills. Furthermore, the written examinations are designed to test both conceptual problems skills and traditional problem solving skills.

Teaching is a central part of academic life. It is a component that plays an important role because it allows the formation of future professionals, and thus, enhances the overall knowledge base. In particular, I see computer science courses reaching an even higher status, since computers and automated processing will continue to increase their impact on human life.

Finally, I believe that a physics curriculum must be integrated in a wide view of the world. A liberal arts education provides this view, allowing the student to become better integrated in the society, to adapt faster and to contribute to the human advancement.

small biological circuits responsible for autonomous activities such as flying, swimming, walking, respiration and many other activities that require fast adaptation to environmental changes without cerebral cortex intervention. I developed new stability criteria for small neural networks (CPGs), and tested the validity of the analytical approach using hybrid circuits designed in collaboration with experimentalists (Dr. Eve Marder at Brandais University, Dr. Vatsala Thirumalai at Beckmann Institute, and Dr. Astrid Prinz at Emory University). I found an analytical solution for phase resetting induced by arbitrary stimuli by using a topological method (published in *Neural Computation*). I subsequently developed a new analytical method for phase resetting based on the Takens method of nonlinear dynamics (published in *Biophysical Journal* and *Neurocomputing*). Analytical and computation models which I developed include high order correction and noise stability analysis (published in the *International Journal of Differential Equations*), and were experimentally tested on the pyloric circuit of lobster (published in the *Biophysical Journal*).

I intend to further develop analytical criterion for the existence and the stability of the phase-locked modes in large cortical networks of neural oscillators. A possible way of generalization of the existing stability criteria is through periodic constraints on coupled oscillators network and the use of circulant matrices theory. Potential applications of phase synchronization studies are related to epilepsy, deep-rain stimulations, and Parkinson disease.

Another direction of research which I intend to pursue is the VLSI implementation of the CPGs for robotic applications. During the last decade the neuromorphic engineering obtained significant successes in designing small legged robots inspired from biology with a very simple but adaptive motion controller using hexapods CPG blueprint. I intend to develop a new class of motion controller for legged robots based on phase resetting correction and not the traditional silicon neurons implementation, the advantage being of a much faster response to environmental changes and wider control parameter range. The price paid for such an enhancement in the overall performance of the artificial CPG is the reduced number of tasks (degrees of freedom) available for the envisioned robot. The first step in the implementation of my idea would be a finite automata machine implementation in simple logical circuits, written either statically in traditional ROM or assembled dynamically in nanocircuits. This research project is closely related to my interest in artificial intelligence and functional selforganization of mobile agents. The neuromorphic CPG is only the first and the simplest layer of robot-environment interaction.

The second layer I envision is based on memory registers and decision making algorithms I already developed and tested for software mobile agents (robot-like ants).

In parallel, I am interested in computational and theoretical models of dopamine neurons. I developed a new computer models for dopamine neurons, which are primarily involved in memory and learning, but also involved in all reward-based activities and drug addiction. I developed a new computational model for dopamine neuron by incorporating physiologically realistic currents such as fast voltage-mediated inactivation of the L-type channels and slow potassium currents suggested by recent studies on the ERG gene.

Complex systems is a topic on which I have been working since my doctoral studies. I am particularly interested in analytical solutions of coupled nonlinear evolution equations for complex systems and the corresponding cellular automata implementations. Decentralized solutions based on swarm intelligence were proposed and tested on small scale networks in telecommunication. The artificial "ants", tiny programs that roam around networks behave much like their living counterparts, updating the routing tables of the telecommunication networks and instantly redirecting the packages across the network in order to avoid traffic jams. To implement software mobile agents, I used a cellular automata approach based on a stochastic learning algorithms and proved that there is an emergent behavior at the level of the team by measuring the increase in the environment’s degree of organization (published in *Journal of Physics A: Mathematical and General*). As a concrete application, I modeled the cooperative behavior of the immune system response to carcinoma using self-organizing cellular automata paradigm (published in *Bioinformatics*). I would like to further develop a global model of carcinoma based on both physiological measurements and the cellular automata implementations, and to this end, I opened a fruitful collaboration with Dr. Ionel C. Baianu at the University of Illinois at Urbana-Champaign. We recently submitted a P50 grant proposal entitled “Complex Systems Biology of Cancer Integrated with Molecular Imaging and Diagnosis” to the U.S. National Institute of Health. Based on my expertise in computer science, I also submitted two grant applications to the U.S. National Science Foundation in order to get financial support for developing new computational paradigms based on functional self-organization algorithm for traffic balancing and efficient routing. The two grant proposals are: “Self-organization of mobile agents: global coherent behavior based on local information analysis" and "Distributed decision-making algorithm for efficient routing and network balancing".

Chaos and Nonlinear Dynamics

I successfully used the embedding theorem for phase space reconstruction of pyloric dilator membrane potential record (published in *Biophysical Journal*). I intend to further develop topological methods for periodic orbits embedding and to implement efficient numerical algorithms for such cases. The problem of reconstructing the (quasi)periodic noisy trajectories is particularly challenging due to the strong sensitivity of the nearby trajectories to small fluctuations. At the same time, running a computer simulation of a chaotic system leads to continual accumulation of small errors due to machine roundoff, making the computed trajectory distinct from the true trajectory. Although the nonlinear phenomena are ubiquitous, the computational paradigms are still relying on the unrealistic hypothesis of "numerical stability to small roundoff errors". One solution I envision to this problem is the implementation of quantum computation algorithms based on recently developed trends in parallel computing.

Besides computational solutions to nonlinear evolution equations, which is the main trend nowadays, I also developed analytical solutions based on Krilov's averaging techniques and time scale separations (published in *Physical Review*). I would like to continue my analytical approach along the following particularly fruitful directions: 1) The generalization of averaging techniques based on curvilinear coordinates, which smoothly transforms the local bifurcation structure into a Riemann surface of zero curvature, 2) The use of Hidden Markov Models to extract the essential information about the original phase space embedding, which proved particularly efficient in detecting the embedding dimension of the underlying dynamics, 3) Improved standard least-square fits to estimate the structural parameter of a low-dimensional deterministically chaotic system (published in *Chaos*), and 4) Implementation of proportional feedback control mechanisms for chaotic systems (published in *Journal of Technical Physics*). Implementing practical control meets serious difficulties because a system at the edge of chaos is sensitive even to small parameter variations. The action of global feedback on chaotic extended systems has been experimentally and theoretically investigated for lasers, gas discharges, semiconductors, populations of electrochemical oscillators, and surface chemical reactions.

Nonequilibrium and Nonextensive Statistics

Recent progresses in the complex systems theory reopened a febrile search for microscopic description of self-organization in the framework of statistical mechanics. A fundamental distinction between the extensive Boltzmann-Gibbs-Shannon and Tsallis non-extensive statistics is the presence of the entropy index q, which is a measure of the distance from a steady equilibrium. I developed a generalized approach on entropy index computation based on generalized Hurwitz Zeta functions (published in *Journal of Physics A: Mathematical and General*). The analytical method developed allowed me to explicitly compute the entropy index for a quantum gas with linear distribution of energy levels. This application of the nonextensive statistics opened the possibility of explicitly connecting the microscopic dynamics and the macroscopic evolution of the system under consideration. From a dynamical point of view, the same results could be obtained by using the Kolmogorov approach to dynamics. I have been working on a generalized correspondence principle between the dynamical approach of Lyapunov and the topological entropy formalism of Kolmogorov-Sinai. Potential applications of the neonextensive statistics are related to nanotechnology and small scale computational units.

Theoretical Condensed Matter

Nonequilibrium surface growth and interface dynamics represent an effervescent area of research with a large number of discrete atomistic growth models and stochastic growth equations exhibiting generic scale invariance characterized by power law behavior (SOC). Diffusion Limited Aggregation (DLA) is the main paradigm used to solve the aggregation of clusters via diffusion and attachment. Electrochemical deposition and Molecular Beam Epitaxy are two examples of general models developed in the context of DLA and implemented using cellular automata algorithms. Molecular Beam Epitaxy is applied in the growth of layered semiconductor heterostructures for electronic devices or in the development of thin magnetic films for novel storage media, and therefore plays a significant role as a tool in the design of nanostructures, such as Quantum Wires or Dots.

The computation I developed for DLA modeling incorporates the traditional Metropolis updating rule subject to detailed balance. The novelty of the proposed approach consist of connecting the macroscopic measures, such as surface roughness, to dynamic quantities, such us the exponent of the two-particle interaction potential. Our preliminary results indicate a deterministic relationship between the fractal capacity dimension and the exponent of the two-particle potential. Therefore, our method could be used in conjunction with the electron microscopy to determine the Hamiltonian at the microscopic level. I intend to extend the applicability of the method for the purpose of microscopic model prediction by including higher-order fractal measures. Also of special interest is the development of numerically efficient implementation of the DLA cellular automata. The initial implementation used Pascal (because of the integrated graphic interface that allows instant graphic visualization of numerical results). More recently the entire implementation was ported to the C language (for fast computation) and interfaced with Mathematica (for easy graphical visualization).

Use of Technology in Classroom.

I am a firm believer in the need for efficient teaching. In the recent decade, the advances in technology and the wide spread of computers have introduces new means of teaching. However, most of these techniques are used inefficiently and do not usually result in improved class outcome. My research interests here are related to the study of linking class presentation and assessment tools to classic educational methods. My research in this field materialized in three books designed to help students enhance their conceptual understanding of physics principles and strengthen their problem solving skills. I am currently developing a set of conceptual problems to be used in conjunction with the "peer instruction" method.

Overall, my research activities will emphasize promoting learning, and teaching. I am continuously involving students in research projects and proving them with the opportunity to learn how to do independent research. My broad research interest is built around the genuine search for unifying physical principle able to hold together and coherently explain the complex dynamics of natural and man-made systems. My search for new paradigms is founded on in-depth physical principles understanding and rigorous computational methodologies.