Curriculum Vitae

Nikola Venkov

PhD Student

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Academic education:

PhD candidate in Mathematics, University of Nottingham, United Kingdom, 2004-present

Recently, I was selected by the University to receive an Andrew Henry Award, in recognition of outstandingPhD research

BSc in Applied Mathematics, University of Sofia "Sv. Kliment Ohridski", Bulgaria, 2000-2004

Graduated with Excellent 5.91 (on a scale from two to six).

Erasmus exchange student (undergraduate), University of Sheffield, United Kingdom, 2003

A six months research project in Solar Magnetohydrodynamics led by professor Róbert von Fái-Siebenbürgen

Research statement: Travelling waves of localised high neuronal activity have been observed in experimental preparations of cortical and thalamic brain slices. In vivo, EEG rhythms and brain activity during epileptic seizures are striking phenomena of large-scale synchronisation of neuronal populations. Using mathematical description of neural tissue by integro-differential equations linking the intrinsic local population dynamics with the nonlocal synaptic coupling between populations one is able to achieve similar type of dynamics. I am studying pattern formation in such nonlocal neural field models by adapting techniques that have been developed in physics for local PDE equations.

Results for more complicated neural field models have not been that common although they are both biologically more realistic and can produce more interesting dynamic patterns. We are interested in models incorporating space-dependent delays (axonal or dendritic) in the biologically relevant regime of local inhibition-distal excitation connectivity, and models involving various types of adaptation, including dynamic thresholds. The additional features allow interesting solutions even for one-population reductions of the models. We have studied globally periodic solutions by Turing-Hopf instability theory, both linear and weakly non-linear (deriving amplitude equations). We have undertaken this analysis for a general 1D model with any time-dependent connectivity allowing us to study models with various types of delays and adaptation. We formulated also the full PDE form and studied instabilities in a 2D multi-population model with axonal delays which is applicable to EEG simulation. Currently we are looking at approaches for understanding localised solutions in 1D and 2D fields. Solutions of models incorporating dynamic threshold have characteristics very similar to dispersive solitons found in various physical systems and we are adapting techniques from those fields to handle integral equations.

Presentations:

A poster, comparison of Amari and Evans approaches for studying bump solutions, presented at *SIAM Conference on Applications of Dynamical Systems*, Snowbird, USA, 28.V - 1.VI.2007
Also on the workshop *Coherent Behavior in Neuronal Networks*, Mallorca, Spain, 17 - 21.X.2007
Review of Rebecca Hoyle's book "Pattern Formation: Introduction to Methods" for Nonlinear News UK, December 2006 issue
A talk at the *Theoretical Neuroscience Network Annual Meeting*, Bristol, UK, 6 - 8.IX.2006
Poster "Amplitude equations for a class of neural field models" at *CNS 2006*, Edinburgh, United Kingdom, 16 - 20.VII.2006
It was presented also on the *Conference on Mathematical Neuroscience*, Andorra, 1 - 4.IX.2006
A talk at *VI. Crimean School and Workshops: Nonlinear Dynamics, Chaos, and Applications*, Yalta, Ukraine, 15 - 26.V.2006
A poster for *Coupled60: A Workshop on Coupled Systems*, Houston, USA, 3 - 6.II.2005, with title "Neural Field Model with Axonal Time-Delay: Generation of Travelling Turing Patterns"
Poster displayed at *Workshop on Mathematical Neuroscience*, Edinburgh, UK, 21 - 23.III.2005
Also at *PFD III: Theoretical Aspects of Pattern Formation*, Guilford, UK, 19 - 23.IX.2005

Attended workshops and summer schools:

Coherent behavior in neuronal networks, Mallorca, Spain, 17 - 21.X.2007
Non-Linear Neurodynamics, University of Exeter, Exeter, UK, 5 - 6.VII.2007
SIAM Conference on Applications of Dynamical Systems, Snowbird, USA, 28.V - 1.VI.2007
Eleventh International Conference on Cognitive and Neural Systems, Boston University, Boston, USA, 16 - 19.V.2007

Theoretical Neuroscience Network Annual Meeting, University of Bristol, Bristol, UK, 6 - 8.IX.2006
Conference on Mathematical Neuroscience, Universitat d'Andorra, Andorra, 1 - 4.IX.2006
Theoretical Neuroscience & Complex Systems Summer School, FIAS, Frankfurt, Germany, 5 - 27.VIII.2006
Fifteenth Annual Computational Neuroscience Meeting CNS*2006, Edinburgh, UK, 16 - 20.VII.2006
VI. Crimean School and Workshops: Nonlinear Dynamics, Chaos, and Applications, Yalta, Crimea, Ukraine, 15 - 26.V.2006 Neuro-IT Cerebellar Modeling Workshop, University of Antwerp, Antwerp, Belgium, 5 - 6.XII.2005
PFD VI workshop: Theory and Applications of Coupled Cell Networks, Isaac Newton Institute, Cambridge, UK, 26 - 30.IX.2005
PFD III workshop: Theoretical Aspects of Pattern Formation, University of Surrey, Guildford, UK, 19 - 23.IX.2005
LMS/EPSRC Short Course on Computational Differential Equations, University of Manchester, Manchester, UK, 11 - 16.IX.2005
2005 Edinburgh Summer School in Neuroinformatics, Edinburgh, UK, 22 - 26.VIII.2005
PFD I training course: Pattern Formation in Large Domains, Isaac Newton Institute, Cambridge, UK, 1 - 5.VIII.2005
JISD2005 course, Universitat Politècnica de Catalunya, Barcelona, Spain, 27.VI - 1.VII.2005
Workshop on Mathematical Neuroscience, Edinburgh, 21 - 23.III.2005

Professional membership:

Isaac Newton Institute (junior member)
London Mathematical Society (associate member)
The Society for Mathematical Biology (student member)
The Society of Industrial and Applied Mathematics (student member)
Nottingham Institute of Neuroscience

Computer languages and programming experience:

Delphi, Pascal, PERL, Javascript and DHTML, MatLab, Maple, XPP

Natural languages:

Bulgarian, English, Serbo-Croat, Russian, German, Spanish

More detailed research description:

I study pattern formation in neural field models. There is a little introduction of these two terms, before describing my work (skip freely to the third paragraph).

Neural field models: In recent years significant progress has been made in understanding brain function by mathematical techniques - on the level of a single neuron dynamics, networks of neurons as well as at the level of neural tissue. Brain cortex could be thought of as a 2-dimensional sheet of tissue of densely interconnected neurons through which propagate spatially-structured impulses of neuronal activity. Thus, mean-field activity models could be applied to explain biological experiments showing activity synchronization throughout the brain, spread of waves or formation of stable patterns of activity. These are non-local models, where the activity at each neuronal population depends on a weighted function of the signal inputs from all other population sites. Neurons communicate by series of spikes which here are averaged into population firing rates. These statistical approximations allow us to describe large-scale neural tissue dynamics (i.e. on the order of millimetres) by continuous mathematical equations often called neural fields, firing rate or mean-field models. They are integro-differential equations involving a differential operator for the synaptic processing, spatial convolution terms for the neuronal input and connectivity, and a nonlinear processing function converting the input firing rates to an output one. A variety of features could be added such as delays, adaptation, etc. Unfortunately, many of the studies of neural fields have concentrated on the biologically unrealistic local excitation-distal inhibition connectivity in order to obtain pattern solutions, an emphasis that we will try to balance.

Pattern formation: The models described above show very rich behaviour of solutions - travelling waves and fronts, bumps, breathers and globally periodic patterns. One part of my research has been to study periodic solutions using the theory of regular pattern formation. It was originally developed in physics to study (for example) convection, and dealt with PDEs. The typical scenario is that we start with a stable homogeneous solution and look for parameters at which the linear analysis tells us it becomes unstable to periodic spatial perturbations, the so called Turing instability. This would lead to growth of inhomogeneous solutions i.e. patterns. However we have no information if the growth will saturate to a finite stable pattern and what will be its final form. The theory of pattern formation exploits the system symmetries to predict the geometry of possible patterns, and further, for parameters near the bifurcation point uses asymptotic expansions to derive the normal form of the bifurcation (amplitude equations). It governs the nonlinear selection between patterns that we will observe in the full system. Typically one would arrive at a system of Ginzburg-Landau equations. A different approach is necessary to study localised patterns such as bumps or breathers. For these one can borrow on the techniques developed in nonlinear PDE systems for dispersive solitons, fronts and interfaces.

My research: In view of the oscillatory patterns obtained by some authors in (one-population) scalar neural fields, we were interested in constructing the normal form for a Turing-Hopf instability in this context. We wanted to investigate what model features are needed to obtain dynamic patterns as opposed to static ones, and to achieve patterns in models with realistic local inhibition - distal excitation (inverted Mexican hat) type of connectivity. We wanted to investigate what model features are needed to obtain dynamic patterns as opposed to static ones, and to achieve patterns in models with realistic local inhibition - distal excitation (inverted Mexican hat) type of connectivity.Further we were curious about the selection between travelling and standing waves. We have developed the weakly nonlinear analysis for a general system that encompasses the class of neural fields with time-dependent connectivities (for example incorporating delays). The relevant amplitude equations were shown to be the mean-field Ginzburg-Landau equations. The generality of our initial work allowed us to apply the results to a wide variety of models suggested in the literature, including extensions with adaptation and two-population models. The theoretical predictions have become the basis for a number of numerical codes that allow us to quickly investigate the parameter space of a new model and, using both the linear and weakly non-linear instability analysis, plot the boundaries of parametric regions in which the homogeneous solution, a static pattern, travelling wave, standing wave or homogeneous (bulk) oscillation is preferred. All models are carefully checked by simulation of the full equations.

We extended our work to multi-population planar neural fields. We were able to derive an exact PDE equivalent form for the model with axonal delays which enabled us to simulate the planar equation and verify the Turing instability analysis. Weakly nonlinear analysis was not pursued due to the large variety of possible patterns in the plane one has to pick. However we looked at a two-population model incorporating patchy connections defined by a regular lattice.

Current and future work: Recently we shifted focus to a neural field with a Heaviside processing function possesing a dynamic threshold. This is a novel model taking into account that neuronal thresholds accommodate to persistent high input making the neurons less responsive to it. This mechanism is a crucial tool of computation in the nervous system. Simulations of the model exhibited a variety of very interesting localised dynamics reminiscent of dispersive solitons in the physical literature - stationary and travelling bumps and breathers, self-replicating dynamics and particle-like scattering between bumps, fingering instability and labirynth formation. We have begun to tackle analytically these intriguing phenomena by adapting weakly nonlinear pulse interaction, Amari technique and interface dynamics.