Final Report for Period: 02/2006 - 06/2006

Submitted on: 12/20/2006

Principal Investigator: Kozma, Robert .

Award ID: 0130352

Organization: University of Memphis

Title:

Percolation Model of Phase Transitions in the Central Nervous Systems during Perceptual Information Processing

Project Participants

Senior Personnel

Name: Kozma, Robert

Worked for more than 160 Hours: Yes

Contribution to Project:

He is the PI and responsible for coordinating the project between mathematical, computational, and neurobiological areas. Within the research areas, he is responsible for modeling and computational aspects of neuropercolation.

Name: Freeman, Walter

Worked for more than 160 Hours: Yes

Contribution to Project:

he is involved in the neuroscience aspects of the model. Providing experimental data and biological motivation for mathematical modeling.

Name: Bollobas, Bela

Worked for more than 160 Hours: Yes

Contribution to Project:

He is Co-PI and responsible for the graph theoretical aspects of the project.

Name: Balister, Paul

Worked for more than 160 Hours: Yes

Contribution to Project:

He is involved in the mathematical and graph theory modeling aspects of the project.

Post-doc

Name: Walters, Mark

Worked for more than 160 Hours: Yes

Contribution to Project:

He worked on the mathematical modeling of neuropercolation. He is partially supported by the present project. Otehr supports coming from DARPA.

Name: Voicu, Horatiu

Worked for more than 160 Hours: Yes

Contribution to Project:

He worked as a postdoc fellow with an appointment of 1 year, on applications of the computational model in the design of autonomous intelligent systems.

Name: Majumdar, Kaushik

Worked for more than 160 Hours: Yes

Contribution to Project:

He participated in the project as a Fullbright Visiting fellow for a period of 9 month. He has been involved in modeling.

Name: Lendasse, Amaury

Worked for more than 160 Hours: Yes

Contribution to Project:

He worked on statistical modeling and data processing of nonlinear time series.

Name: Demirer, Murat

Worked for more than 160 Hours: Yes

Contribution to Project:

He has been involved on biomedial signal processing aspects and filter design for nonlinear and nonstational EEG data.

Graduate Student

Name: Chen, Hui

Worked for more than 160 Hours: Yes

Contribution to Project:

He is a graduate student working on the computational model of the project.

Name: Majumdar, Nivedita

Worked for more than 160 Hours: Yes

Contribution to Project:

She has graduated as MSc last Summer and this fall she started to work on the project. She is a potential PhD candidate.

Name: Puljic, Marko

Worked for more than 160 Hours: Yes

Contribution to Project:

He completed his PhD in this project area. He was responsible for the computational model. Also he maintains the computer system (16 processor parallel computing) as well as the project web page.

Name: Wong, Chuen

Worked for more than 160 Hours: Yes

Contribution to Project:

He has been Graduate student who conducts computer simulations.

Name: Beliaev, Igor

Worked for more than 160 Hours: Yes

Contribution to Project:

Graduate student working on time series analysis and chaos modeling. His task is maintaining the Neurodynamics Toolbox developed in MATLAB environment.

Name: Ilin, Roman

Worked for more than 160 Hours: Yes

Contribution to Project:

Graduate student working on stability issues and modeling nonlinear dynamic systems.

Name: Myers, Mark

Worked for more than 160 Hours: Yes

Contribution to Project:

Graduate student (MSC and PhD) for modeling EEG signals and establishing and maintaining clinical collaboration relevant to this project.

Name: Aluri, Ashok

Worked for more than 160 Hours: Yes

Contribution to Project:

Graduate (MSc) studnet for neuropercolation model simulations, in particular using the high-performance computing facilities.

Name: Rodriguez, Jose

Worked for more than 160 Hours: Yes

Contribution to Project:

Graduate student (MSc) for signal processing and modeling aspects of EEG data.

Name: Wilburn, Tracey

Worked for more than 160 Hours: Yes

Contribution to Project:

Graduate student (MSc) working on biomedical application of intelligent signal prcessing.

Undergraduate Student

Technician, Programmer

Name: Silver, Charlie

Worked for more than 160 Hours: No

Contribution to Project:

He is involved in coordinating the interdisciplinary and outreach activies of this research project as part of the Computational Neurodynamics Lab activities.

Name: Burke, Brian

Worked for more than 160 Hours: Yes

Contribution to Project:

Brian Burke works in the Lab of Dr Freeman at UC Berkeley as programmer. His task is to analyze EEG and MEG data and develop computational models.

Other Participant

Research Experience for Undergraduates

Name: Nordstad, Julia

Worked for more than 160 Hours: Yes

Contribution to Project:

REU work on data base development and management for various data resources, like EEG and simulations.

Years of schooling completed: Junior

Home Institution: Same as Research Site

Home Institution if Other:

Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree

Fiscal year(s) REU Participant supported: 2005

REU Funding: REU supplement

Name: Scaiffe IV, Lewis

Worked for more than 160 Hours: Yes

Contribution to Project:

As REU sudent he has been involved in neuropercolation simulations research.

Years of schooling completed: Sophomore

Home Institution: Same as Research Site

Home Institution if Other:

Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree

Fiscal year(s) REU Participant supported: 2006

REU Funding: REU supplement

Organizational Partners

University of California-Berkeley

Dr WJ Freeman Neurophysiology Lab at UCB is involved in the project. They provide data resources on EEG and computational support through a programmer.

Other Collaborators or Contacts

Dr Peter Erdi, Henry R. Luce Professor of Complex Systems
Center for Complex System Studies, Kalamazoo College
and Head of Department of Biophysics, Hungarian Academy of Sciences, KFKI Research Institute Budapest, Hungary
Dr Erdi is well-known expert of brain dynamics. We collaborate with him on developing the proper approximation of brain dynamics to be applied in our model.

Dr Prasun K. Roy, National Brain Research Center, Delhi, India and
Prof. D. Dutta Majumder, Indian Statistical Institute, Calcutta, India
We have completed recently a work with Dr Roy and Dr Majumder on oscillation-induced instability and phase transitions in biological systems. This work deals with it operation of the immune system, and some of its conclusions are relevant for the work in the present projects on brain studies.

Dr. M.D. Holmes, University of Washington, Harbor View Hospital, Seattle, WA
Based on the analysis and evalaution of data obtained by Dr Holmes, we have elaborated principles of information encoding during cognitive processing in brains, which are used as important reference points in theoretical model building.

Dr. Jose Principe, Bell South Professorm Computational Neuroengineering, University of Florida, Gainesville, Fl.
Dr Principe is a leading expert on neural networks and its hardware implementation. We are collaborating with him on the chip implementation of chaotic neurodynamics, which is a crucial future step and natural continuation/extension of our present study.

Sampsa Vanhatalo, University of Finland, Helsinki, Finland
Dr. Vanhatanlo is an experienced electroencephalographer. He has participated in EEG data acquisition and evaluations while working with Dr Holmes at University of Washington, Seattle.

Dr. Robert Johnson, Department of Mathematics, London School of Economics, London, UK
Dr Johnson is a collaborator in the research work on neural percolation models.

Activities and Findings

Research and Education Activities:

Major Research Activities

This is a strongly interdisciplinary project, including the following disciplines: neurobiology, computer science and information processing, and mathematical modeling. Our research has also important implications in engineering, in particular in robot control, as it will be described in the section of Contribution to other disciplines in engineering and science

1. Analysis of biological data on spatio-temporal brain activity (Area Coordinator Co-PI WJ Freeman)

Year 1:
Description of electrophysiological phenomena in the brains of animals and of human volunteers, in conjunction with learning and intentional behavior. These phenomena indicate that cognitive processing occurs discontinuously in brains, with spatial frames of cognitive content forming in succession at rates of 6 - 10 Hz. The formation appears to occur by a first order phase transition that can be modeled as a subcritical Hopf bifurcation generalized to chaotic oscillations. The analyzed data are the results of previous experiments on rabbits at UC Berkeley in the laboratory of Dr Freeman, completed in the NIMH grant MH06686 years ago, and on human volunteers at the University of Washington, Harbor View Hospital (conducted by Dr. M.D. Holmes).

Year 2:
EEG data were obtained from subjects with eyes open or closed, either at rest or sustaining low-level electromyographic potentials (EMG) from scalp muscles. High-density arrays of electrodes were fixed intracranially (8x8, 10x10 mm, spacing 1.25 mm) on the superior temporal gyrus of a candidate for surgery to treat intractable epilepsy, or extracranially on the scalp of 9 normal volunteers (1x64 linear array, 189 mm in length with 3 mm spacing). The data were digitized at 5 ms intervals and for each subject from Seattle to Berkeley for analysis.

Year 3 and beyond:

Extensive evaluation of EEG data by measuring frequency and phase using the Hilbert method at each digitizing step and by the Fourier method in a moving window stepped along the filtered signals at the digitizing interval (5 ms). These measures enabled calculation of the location, size, time of onset, phase velocity, duration, and recurrence interval of radially symmetric spatial patterns named as phase cones. The apex of each cone showed the location and onset time of abrupt re-initialization of phase at a frequency in the beta-gamma range. Half power cone diameters were 5-50 mm or more. Durations had fractal distributions with means ranging from 6-300+ ms depending on window length. Recurrence rates of longer-lasting phase cones were in the theta-alpha range.

2. Modeling and simulation of phase transitions in random media (Area Coordinator R Kozma, PI):

Year 1:
Computational models of random effects on the dynamical behavior of 2-dimensional lattices are developed. These are called neuropercolation models, and they are the generalizations of other dynamical models, like Conway's game of life, bootstrap percolation, and Hopfield memory arrays. Our simulations are directed toward analyzing threshold phenomena in neuropercolation models, which have very close similarity with phase transitions in physical systems, like Ising models. The role of the background noise as control parameter for the dynamics is studied. Simulations have been conducted to interpret the observed phase transitions in brain dynamical behavior. The simulations used the cluster of workstations with 16 parallel processors, which are available at the PI's Computational Neurodynamics Laboratory at the University of Memphis.

Year 2:
Simulations have been conducted with moderate lattice sizes of up to 256x256. We performed analysis of phase transition near and far away from the critical point in the space of random percolation rule and nonlocality of the cell-to cell interaction. Extensive studies are conducted to identify ontogenetic development of collective behavior in neuropercolation models. We studied the parameter space of noise level and the relative ratio of long axons. This latter parameter is the manifestation of small-world effects in cortical layers.

Year 3 and beyond:
Computations have been performed using both excitatory and inhibitory nodes, in order to generate non-trivial oscillations in 2d lattices. In these models 3 control parameters have been identified and extensively studied: (1) background noise level, (2) long axon rate, (3) sparseness of excitatory-inhibitory cross-links between populations. The following statistical properties of the simulated systems have been evaluated: conditions of (intermittent) synchronization, clustering and cluster size distribution. We tested the conditions for producing 1/f^a type power spectral densities, which are hallmarks of various cognitive activities in neurophysiology experiments.

3. Mathematical modeling of phase transitions in random cellular automata (Area Coordinator: Bela Bollobas, Co-PI):

Year 1:
The rigorous mathematical analysis of phase transitions in random models poses a very difficult problem. We have studied mean field models, which allow a theoretical description of the onset of phase transitions and the behavior of the system near the critical point. As the next step, we studied local random cellular automata models. The Toom cellular automaton is one of the very few examples of local models, in which a thorough mathematical analysis has been successful. Using the biological intuition based on the observed neurophysiological processes in the neuropil, we develop a mathematical model of phase transitions in local models. These activities are conducted on the University of Memphis campus, and partly in the Theory Group of Microsoft Research, Seattle campus and Cambridge University, UK.

Year 2:
Theoretical efforts have been concentrated on two major fields: (1) mean-field models with non-local connections allow a thorough theoretical understanding of the behavior for a wide range of control parameters; (2) in the case of local models, the case of small perturbations have been investigated. The obtained rigorously proven mathematical results support the biologically motivated conjecture about the very rapid phase transitions in local and non-local models.

Year 3 and beyond:
Random graph methods have been widely used and cited in the description of small-world effect and scale-free behavior in real-world networks. Unfortunately, the existing approaches in the literature often lack mathematical rigor and can produce misleading results. We developed a general framework of the application of random graphs for various 2-dimensional planar network applications in a mathematically consistent way. We use the following major components: distribution of nodes, distribution of the length of edges, degree distribution across nodes. After specifying these components, various behaviors of interest can be derived, e.g., as scale-free behavior, hub structure, the existence of cycles of given length, etc.

Major Educational Activities

1. Academic coursework

There are several courses at the University of Memphis, which benefit directly from this research in various ways. These graduate courses include Neural Networks, Computational Intelligence, Advanced Algorithms, Cognitive Science Seminar, Combinatorics Seminar. The lecturers, who work on our project, introduce from time-to-time the relevant results of our research to the students. In addition, some students choose class project topics that are related to this research. In this way students get a direct exposure to the newest developments in this exciting field. The undergraduate course of 'Soft Computing,' which benefits from the results of this project in the area of network theory and its applications.

2. Students' research involvement

Thorough the project duration, about a dozen of students, mostly graduates, have been involved in the research. As the result, one PhD dissertation (M Puljic) and a MSc Thesis (M Myers) has been produced, together with several additional final projects for CS graduate students. Students have been continuously involved in the research through the weekly seminar of the Computational Neurodynamics (CND) Lab. At the CND research seminar students affiliated with this NSF project, as well as with other related projects (NASA, DAPRA) come together and present their results to this broader audience. The students also had the opportunity to attend workshops, winter schools, conferences, to present their results.

Findings:

MAJOR FINDINGS

1. We have analyzed the behavior of the neuropercolation model in the case of local neighborhoods and majority voting updating rule. We have shown that the model shows a behavior that resembles the Ising model of statistical physics. We have estimated the critical exponents, including magnetization, susceptibility, and correlation length. The estimated parameters satisfy a hyperscaling relationship and indicate that our model does not belong to the thoroughly studied Toom cellular automata, neither to the strong or weak Ising universality classes, rather it is of a weak-Ising class.

2. We have incorporated nonlocal connections into our neuropercolation model. Nonlocal connections are important components of neural systems, which correspond to long axons that allow communication between various cortical regions. We have shown that the non-local connectivity acts as a control parameter, together with the probabilistic component of local interactions (noise). We have constructed the phase diagrams in the space of non-local connectivity and local noise. Near the critical point, a small change in the non-local connectivity (gain) will lead to drastic alteration of the dynamical behavior of the system.

3. We have studied mean field models of probabilistic cellular automata. Very little has been proven rigorously about these models in the literature. We have shown the existence of phase transition is a wide class of mean field models. We have also shown the onset of interesting phenomena, like symmetry breaking in various mean field models.

4. Developed theory of random majority percolations with weak noise term. In this model, each site follow the majority rule with high probability. The lattice resides most of the time in one stable state or the other. From time-to-time, it can flip between these states. Until now it was unclear how long it takes to transit from one state to the other. We gave a rigorous proof of the fact that the model spends a long time in either low- or high-density configurations before crossing very rapidly to the other state. We have been able to prove fairly good bounds on the very long time the model spends in the two essentially stable states.

5. We shown that the transition between the quasi-stable states takes a very short time and gave an estimation of this time. This result gives a theoretical justification of the terminology 'neuropercolation' introduced at the start of the project. The obtained rigorously proven mathematical results support the biologically motivated conjecture about the very rapid phase transitions in local and non-local models.

6. Cortical state changes indicated in animals and humans the presence self-organized for cortical regions maintaining metastable states close to instability. This theory to cortex is suggested by the 1/f form of the temporal and spatial spectra from the EEG, indicating power law scaling. Changes in state occur repeatedly at all scales of time and space from those of single neurons through those of the mesoscopic states of wave packets to that of the entire forebrain. We showed that the neuropercolation model exhibits 1/f-type behavior and can be used to interpret neuroscience observations of self-organization of brain dynamics.

7. We have studied the spatio-temporal structure of phase transitions in our local and nonlocal neuropercolation models and compared it to observations in brains. Important common feature of the computational and biological systems is the way the system oscillates for a prolonged time before phase transitions. Once the transition starts, however, the state of the system chages very rapidly. In brains this takes less than about 5-10 ms. We can observe this fast transition in neuropercolation; i.e., the change percolates through the system apparently defying reversibility.

8. We have evaluated spatial and temporal spectra of scalp EEG and EMG from awake humans. Scaling of PSDt from scalp resembled that from pia: near-linear decrease in log power with increasing log frequency (1/f^a). Scalp PSDx decreased nonlinearly and more rapidly than PSDx from pia. Peaks in PSDt (especially 4-12 Hz) and PSDx (especially 0.1-0.4 cycles/cm) revealed departures from 1/f^a. A criterion for measuring EMG may support biofeedback for training subjects to reduce their EMG.

9. Analytic amplitude (AA) and phase (AP) were calculated in scalp EEG of beta-gamma oscillations. State transitions at alpha-theta rates have been observed at each time step for the 64 channels in the analog pass band of 0.5-120 Hz. AP differences approximated the AP derivative (instantaneous frequency). The sizes of temporal AP differences were usually within 0.5 radian from the average step corresponding to the center frequency of the pass band. Large AP differences were often synchronized over distances of 6 to 19 cm. Synchronized AP jumps recurred in clusters at alpha and theta rates in resting subjects and with EMG.

10. Subdural EEG measurement gave estimates of two fundamental state variables at each point in time: the rate of change in phase with time (the frequency), and the rate of change in phase with distance (the gradient). These 2 quantities enabled description of intermittent spatiotemporal patterns of phase. The diameters, durations, and phase velocities of these patterns varied with window duration and with interelectrode interval. Beta-gamma phase patterns in the ms-mm to m-s ranges are evidence that neocortex maintains a scale-free state of self-organized criticality in each hemisphere as the basis for its rapid and repetitive integration of sensory input with experience.

11. The Hilbert transform was used to calculate the analytic amplitude, A, of 64 EEG signals after spatial and temporal filtering in the beta-gamma range. Minimal changes in the spatially-distributed amplitudes coincided with minima in phase dispersion found with the Hilbert transform and gave a measure of synchrony among multiple EEG signals. This was far simpler to compute than phase distributions and showed that maximal amplitude coincided with maximal synchrony.

12. Spatiotemporal infrastructure of phase in human intracranial EEG has been analyzed. Frequency and phase were measured by the Hilbert method enabled calculation of phase cones. Phase cones reflect chaotic state transitions leading to new cortical patterns assimilating sensory input. The overlapping cones show that neocortex maintains a stable, scale-free state of self-organized criticality by homeostatic regulation of neural firing, through which it adapts instantly and globally to rapid environmental changes. The proposed mechanism for stabilization of hemispheric neurodynamics may open new avenues to study human cognition and dynamic brain diseases. The present results also suggest that phase structures in the human scalp EEG relating to cognition may be readily accessible with standard clinical EEG equipment.

Training and Development:

Faculty members benefit from the results of this research in their teaching and development as they regularly use the up-to-date research results in enriching their courses. The courses taught include neural networks, computational intelligence, advanced algorithms, and various seminars.

Graduate students, who work as research assistants for the project, have first-hand experience with cutting edge research topics and research methodology. Other students also benefit from this research via their studies in the courses taught by project team members,. Moreover, the developed software tools in Matlab environment are made available for public use and students' practice in the computer lab. During the weekly seminar of the Computational Neurodynamics (CND) Lab about 8-10 graduate students participate and benefit from the discussions.

Our graduate students and postdoc attended the Winter Schools on Chaotic Communications in San Diego in 2002 and 2003 (H Chen and M Puljic, respectively), and the Understanding Complex Systems Conference at UIUC Urbana in 2004 and 2005 (M. Puljic, M. Demirer), as well as International Neural network Conferences (N. Majumder, R. Ilin, I. Beliaev, M. Puljic) in the project period 2002-2005.

Outreach Activities:

Neuropercolation Model of Cortical Phase Transitions û Dynamics of Cognition and Intelligence, Keynote Talk at Chaos & Complex Systems Symposium May 12-13, 2006, Istanbul, Turkey

Influence of Criticality on 1/f^a Spectral Characteristics of Cortical Neuron Populations, Proc. IEEE World Congress on Computational Intelligence, July 16-21, 2006, Vancouver, Canada, IEEE Press, 2006.

Studies on Sparse Array Cortical Modeling and Memory Cognition Duality, Proc. IEEE World Congress on Computational Intelligence, July 16-21, 2006, Vancouver, Canada, IEEE Press, 2006.

Noise-Mediated Intermittent Synchronization of Collective Behaviors in the Probabilistic Cellular Automata Model of Neural Populations, 10th Artificial Life Conference ALIFEX, June 3-7, 2006, Bloomington, IN, MIT Press.

Neurodynamics Methods for Analysis and Control of Cognitive Behaviors, Workshop organized at 10th Artificial Life Conference ALIFEX, June 3-7, 2006, Bloomington, IN.

'Self-Organized Development of Autonomous Adaptive Systems,' Distinguished Lecturer at Navy Center of Applied Research in Artificial Intelligence, Invited Talk at NCARAI, Navy Research Laboratory NRL, May 9, 2005, Arlington, VA.

'Neurodynamics and Intentional Dynamical Systems,' Special Session Organizer at IEEE Int. Conf. on Neural Networks, IJCNN'05, July 30-August 4, 2005, Montreal, Canada.

'Spatio-Temporal Neurodynamics,' Workshop Co-Chair at IEEE Int. Conf. on Neural Networks, IJCNN'05, July 30-August 4, 2005, Montreal, Canada.

'Role of Noise in Dynamical Models of Biologically-Inspired Computing,' Invited Talk at Complex Systems Seminar, Dept. Mathematics, Hokkaido University, January 11, 2005, Sapporo, Japan.

'Neuropercolation Models of Brain Dynamics,' Invited Talk at Computational Neuroscience Seminar, Northwestern University, November 4, 2004, Chicago, IL.

'Dynamical Systems Approach to Decision Making in a Network of Distributed Autonomous Agents,' Panelist at a Workshop on Networked Robotics: Issues, Architectures, Applications, IEEE/JRS Int. Conf. on Robotics and Applications IROS'04, September 26, 2004, Sendai, Japan.

'Intentional Dynamic Systems Approach to Intelligent Robots,' Invited Talk at Div. Robotics and Mechatronics, Nagoya University, September 27, 2004, Nagoya, Japan.

'Nonlinear Spatio-Temporal Neural Dynamics,' Workshop Chair at Int. conf. Computational Neuroscience CNS*2004, Baltimore, MD, July 21, 2004.

4 Feb, 2003 - Gainesville, ECE Dept. 'Phase transitions spread by anomalous dispersion in cerebral cortex'.

5-7 Feb, 2003 - Gainesville FL - University of Florida McKnight Brain Institute. Conference on Quantitative Neuroscience. 'Phase transitions in cortex initiate perception from sensation'

27-28 Feb, 2003 - Memphis TN - Symposium: 'Dynamics of Perception and Cognition' 'Phase transitions in cortex initiate perception from sensation', Co-sponsored by NSF grant and NASA Intelligent Systems Program [organizer: Kozma]

17-18 Apr, 2003 - Lyon - Dept of Physiology - Remi Gervais 'The olfactory bulb as a model for the dynamics of perception '

24-26 Apr, 2003 - Rome, Catholic University - Congress of the Association of European Psychiatrists: Biological fundaments of memory, Assessment of memory, Psychopathology of memory, Memory and Neuropsychiatric disorders, Therapeutic strategies. 'The neurodynamics of the construction of memories gives opportunities for mistakes and failures' 'Implications from nonlinear neurodynamics for nosology and treatment of psychiatric disorders'

28 Apr, 2003 - Italian Swiss University, Mondrisio - Nicoletta Sala: 'Chaos, mind and Complexity'

29 Apr, 2003 - Milano - Giovanni Degli Antoni (University of Milan - Crema) 'New developments in analog computing based in nonlinear brain dynamics'

15-17 May, 2003 - San Francisco - Soc. Biol. Psychiatr. Mapping scalp EEG with high temporal and spatial resolution.

30 May-2 June, 2003 - Memphis TN, 7th ASSC - 'High resolution EEG brings us another step closer to the NCC'

31 May, 2003 - Memphis - Plenary, Tutorial on Spatiotemporal Analysis of EEG with Rodrigo Quiroga

6 June, 2003 û Hong Kong, Chinese University - 'The Neurodynamics of Perception as Revealed by Human Scalp EEG'.

9-13, 2003 June - Shanghai PRC - INTERNATIONAL SYMPOSIUM ON NONLINEAR SCIENCE AND APPLICATIONS 'Phase transitions in cortex mediate integration of sensory stimuli into perceptual experience.'

12 -13, June, 2003 - Seattle WA - Harborview Hospital Univ. Wash. 'Scalp EEG may reveal spatial patterns in frames flickering at the speed of thought'

18-22 June, 2003 - New York, OHBM 'Can scalp EEGs reveal spatial patterns in frames flickering at the speed of thought?'

21-27 June, 2003 - Wildbad Kreuth, Germany - Workshop 'Construction of meaning from sensory information by repeated state transitions in perception'

30 June, 2003 - Freiburg i/B IGPP- 'Can scalp EEGs reveal spatial patterns in frames flickering at the speed of thought?'

8 July, 2003 - Alicante - Spain - Workshop 'Nonlinear spatio-temporal neural dynamics - Experiments and Theoretical Models' and part of 2003 Computational Neuroscience Conference CNS*03 [Workshop co-organized by Kozma and Erdi]

20-24 July, 2003 Portland OR - IJCNN'2003, Portland û 'A neurobiological theory of meaning in perception', Tutorial on Neurodynamics [by Freeman and Kozma]

8-10 Aug, 2003 û Boston MA - Society for Chaos Theory in Psychology & Life Sciences - 13th Annual International Conf. 'Scalp EEGs reveal large spatial patterns with the texture of gyri in frames flickering at the speed of thought'

12 Sept, 2003 ûUniv. D³sseldorf û High spatial and temporal resolution of scalp EEG'

15 Sept, 2003 û Amsterdam. AMC - 'Fine spatiotemporal resolution of analytic phase reveals episodic synchronization by state transitions in beta-gamma EEGs recurring at alpha-theta rates'

16 Sept, 2003 û Frankfurt û MPI û Scalp EEG at high resolution gives evidence for re-synchronization of beta-gamma activity at alpha-theta rates

17 Sept, 2003 û T³bingen, MPI û A neurobiological theory of meaning.

25 Sept, 2003 û Bethesda MD, NINDS - Spontaneous EEG from intracranial arrays in animals and humans and scalp arrays on humans

26-30 Sept, 2003 - Cary NC - JCIS2003 û Plenary û High resolution scalp EEG in Humans, Symposium: Brain-like architectures for computers

12-19 0ct, 2003 û Miami Beach, American Academy of Child & Adolescent Psychiatry, Symposium on 'The biology of interaction: Genes, Environment and the brain' û 'A biological theory of brain function for psychiatry and psychotherapy'.

9-13 Nov, 2003 û Shanghai, SARS û 'A Biological Theory of Meaning in Perception'

14 Nov, 2003 û Hangzhou, Zhejiang Univ - 'Applications of nonconvergent   - 'chaotic' û dynamics for self-organized control of autonomous devices'.

20 Nov, 2003 û Hong Kong, City Univ û 'Mechanisms of stability in self-organizing dynamics of the brain'

Nonconvergent Neural Memories for Robust Encoding of Noisy Sensory Data, Invited Plenary talk at ANNIE'2003 Conference, November 2-5, 2003, St. Louis, MO.

Biologically Inspired Computing û Past, Present, & Future, Invited Talk at The Inst. Of Complex Systems, Kalamazoo College, MI, October 13, 2003.

'Biologically Inspired Computational Models,' Panel Discussion at IJCNN'03, July 20-24, 2003, Portland, OR

Neuropercolation: Dynamical memory neural Networks û Biological Systems and Computer Implementations, Tutorial at IJCNN'03, July 14, 2003, Portland, OR.

Temporal Aspects of Information Encoding in NNs, Special Track with 3 sessions, co-organizer with Deliang Wang and Ali Minai, at IJCNN'03, July 14-19, 2003, Portland, OR.

Nonlinear Spatio-temporal Neurodynamics, Workshop Organizer with Peter Andras and Peter Erdi at Computational Neuroscience Conference CNS*2003, July 4-8, 2003, Alicante, Spain.

'Dynamical Cognitive Principles, Models, and Implementations,' Invited Talk at NSF Conference on 'Advanced Computation Inspired By Biological Processes,' April 6-8, 2003, Arlington, VA.

Neuropercolation Model of Spatio-Temporal Neurodynamics, at the Workshop Organizer on 'Complex Nonlinear Neural Dynamics,' Computational Neuroscience CNS*2002 Conference, Organizer with P. Andras, and A. Assadi, July 25, 2002, Chicago, IL.

Self-organized development of behaviors in spatio-temporal dynamical systems, Invited talk at Special Session at IEEE World Congress on Computational Intelligence WCCI2002, May 12-17, 2002, Honolulu, Hawaii.

'Your Method is Connectionist Too', Panelist at World Congress on Computational Intelligence WCCI'02/IJCNN'02, May 11-15, 2002, Honolulu, HI.

Neuropercolations: Dynamical percolation Models of Phase Transitions in Physical and Biological Systems, Invited Talk at BISC Seminar, Berkeley Initiative in Soft Computing, UC Berkeley, February 21, 2002.

Journal Publications

W J Freeman, "A neurobiological theory of meaning in perception. Part 1. Information and meaning in nonconvergent and nonlocal brain dynamics.", International Journal of Bifurcation and Chaos, p. 2493, vol. 13, (2003). Published

Freeman WJ, Holmes MD, Burke BC, Vanhatalo S., "Spatial spectra of scalp EEG and EMG from awake humans.
", Clinical Neurophysiology, p. 1055, vol. 16, (2003). Published

Freeman WJ, Burke BC, Holmes MD., "Aperiodic phase re-setting in scalp EEG of beta-gamma oscillations by state transitions at alpha-theta rates.", Human Brain Mapping, p. 248, vol. 19, (2003). Published

Freeman WJ, "The wave packet: An action potential for the 21st Century.
", Journal of Integrative Neuroscience
, p. 3, vol. 2, (2003). Published

Roy, P.K., Kozma, R., Majumder, D.D., "From Neurocomputation to Immunocomputation - A model and algorithm for fluctuation-induced instability and phase transition in biological systems", IEEE Transactions in Evolutionary Computing, p. 292, vol. 6, (2002). Published

Kozma, R., Freeman, W.J., "Classification of EEG Patterns Using Nonlinear Neurodynamics and Chaos", Neurocomputing, p. 1107, vol. 44-46, (2002). Published

Kozma, R., Freeman, W.J., Erdi, P., "The KIV Model - Nonlinear Spatio-temporal Dynamics of the Primordial Vertebrate Forebrain", Neurocomputing, p. 819, vol. 52-54, (2003). Published

Freeman, W.J., "Evidence from human scalp EEG of global chaotic itinerancy.", Chaos, p. 1067, vol. 13, (2003). Published

Freeman, W.J.,, "A neurobiological theory of meaning in perception. Part 2. Spatial patterns of phase in gamma EEG from primary sensory cortices reveal the properties of mesoscopic wave packets.", International J. Bifurcation and Chaos, p. 2513, vol. 13, (2003). Published

Freeman WJ, Ga?l G, Jornten, R., "A neurobiological theory of meaning in perception. Part 3. Multiple cortical areas synchronize without loss of local autonomy.", Int J Bifurc Chaos, p. 2845, vol. 13, (2003). Published

Freeman WJ, Burke BC., "A neurobiological theory of meaning in perception. Part 4. Multicortical patterns of amplitude modulation in gamma EEG", Int J Bifurc Chaos, p. 2857, vol. 13, (2003). Published

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Freeman, WJ, "Origin, structure, and role of background EEG activity. Part 1. Analytic amplitude", Clinical Neurophysiology., p. 2077, vol. 115, (2004). Submitted

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http://www.scholarpedia.org/article/Neuropercolation
Description:

Other Specific Products

Contributions

Contributions within Discipline:
Contributions within discipline

We develop a biologically-inspired dynamical memory model. This is a multi-disciplinary area involving neurobiology, computer science and information technology, and mathematics. Therefore, the disciplinary contributions are listed according to these 3 main areas:

NEUROBIOLOGY:
Outlines a novel experimental methodology of brain monitoring based on dense-array scalp or intracranial EEG measurements. This leads to the identification of frequent (6-10 Hz) sudden jumps (phase transitions) in brain operation. The jumps are the manifestation of higher cognitive activity of animals and humans. Accordingly, brains operate discontinuously, based on a cinematographic principle. In this theory, each image is manifested as quasi-stable spatial amplitude distribution of activity, maintained for about 100-150 ms. These frames correspond to periods of higher cognitive functions, and they are separated by brief de-synchronization of large-scale activity (5-10 ms) which acts as the shutter.

MATHEMATICS/GRAPH THEORY:
We have extended the framework of standard bootstrap percolation to probabilistic models. Our model generalizes previously used models, like cellular neural networks, cellular automata, and bootstrap percolation. The model we develop provides an alternative way of representing and solving mathematical problems using a large number of functionally simple processing units. The key mathematical result shows that random cellular automata undergo spontaneous phase transitions. We gave fairly good bounds both for the waiting time in the quasi-stable states and the time needed to transition to the next state. The theory produces results which are far ahead of our present computational capabilities, and remains so at least for 10-20 years into the future.

COMPUTER SCIENCE/INFORMATION THEORY:
The developed neuropercolation model is a general computational device based on the biologically-motivated principle of computing using chaotic spatio-temporal encoding. Neuropercolation-based computing is drastically more powerful that present day digital computers. Neuropercolation is based on the principle of phase transitions of spatio-temporal patterns, instead of numbers. The proposed approach provides a solution to the notorious symbol grounding problem, by embedding a high-level symbolic representation into a dynamic system.

Symbols emerge intermittently in the form of a distributed amplitude patterns, and they dissolve immediately as they appear under the destabilizing effect of the collective dynamics of array elements.

Contributions to Other Disciplines:

Contributions to Other Disciplines

PHYSICS/COMPLEX SYSTEM/SOCIAL NETWORKS:
Since the late 90's, network theory showed significant advances, based on heuristic principles including scale-free dynamics, small-world dynamics. Those approaches gained popularity in the wide scientific community, however they has several inherent shortcomings due to the lack of systematic mathematical basics. Our neuropercolation model provides a solid mathematical approach to understand the behavior of these models and to go beyond their shortcomings.

MENTAL HEALTH/COGNITIVE DEVELOPMENT:
We suggested a novel experimental method to monitor cognitive activity base don scalp and intracranial recordings. The proposed mechanism of hemispheric neurodynamics may open new avenues to study human cognition and dynamic brain diseases. The present results also suggest that phase structures in the human scalp EEG relating to cognition may be readily accessible with standard clinical EEG equipment. This approach for brain-computer interfaces has the potential of practical applications in various areas, e.g., supporting persons with disabilities.

HARDWARE/ROBOTICS:
Our results contribute to the development of novel computer hardware devices. This includes micro-chip implementation of chaotic memory devices for improved capacity and robustness, with applications in robotics and autonomous systems design.

Contributions to Human Resource Development:

The research students working on the project will acquire advanced skills that will be essential in their future career.

Contributions to Resources for Research and Education:

We have established a 16-node parallel computing cluster which is very useful tool that is used in various research and educational projects.

Contributions Beyond Science and Engineering:

Neuropercolation is a new approach to mathematical modeling and computation and it will change all aspects of the economy, organizations, and the society. Robotics applications help to space explorations and extend the reach of humanity beyond Earth, towards planetary missions.

Categories for which nothing is reported:

Any Product