Contents

1 Introduction .............................................................................................................. 5
2 Personnel ................................................................................................................... 6
3 Boards ........................................................................................................................ 9
   3.1 Centre of Excellence Scientific Advisory Board ............................................... 9
   3.2 Internal Research Board “Oldies” ...................................................................... 9
4 Teaching .................................................................................................................. 10
5 Theses....................................................................................................................... 11
6 Research Projects ................................................................................................... 12
   6.1 Models and Methods ........................................................................................ 16
      6.1.1 Complex Networks and Agent-Based Models ...................................... 17
      6.1.2 Complex Dynamics and Statistical Physics .............................................. 20
      6.1.3 Statistical Brain Signal Analysis ............................................................. 22
   6.2 Engineered and Artificial Systems ................................................................... 24
      6.2.1 Engineered Nanosystems ...................................................................... 25
      6.2.2 Modelling of Learning and Perception .................................................. 29
      6.2.3 Computational Neuroscience ................................................................. 34
   6.3 Cognitive and Social Systems .......................................................................... 40
      6.3.1 Cognitive Systems ................................................................................. 42
      6.3.2 Structure and Dynamics of Social Networks ......................................... 46
   6.4 Computational Health ...................................................................................... 48
      6.4.1 Bayesian Modelling and Applications ................................................... 49
   6.5 Wolfson College, Oxford: Advanced Computational Science and Engineering 54
7 Research Activities.................................................................................................. 55
   7.1 Visits to the Laboratory .................................................................................... 55
   7.2 Visits by the Laboratory Personnel ................................................................. 55
   7.3 Participation in Conferences and Seminars ...................................................... 56
   7.4 Memberships in Scientific Societies ................................................................. 59
   7.5 Other Activities ................................................................................................ 60
8 Publications ............................................................................................................. 62
   8.1 Publications in Refereed Journals .................................................................... 62
   8.2 Conference Proceedings and Abstracts ............................................................. 64
1 Introduction

Year 2009 marks the second year after the Laboratory of Computational Engineering (LCE) as the Centre of Excellence in Computational Complex Systems Research (COSY) and Laboratory of Biomedical Engineering joined forces to form the Department of Biomedical Engineering and Computational Science (BECs) as part of the Faculty of Information and Natural Sciences, in the School of Science and Technology of Aalto University. With this new structure COSY (as an autonomic part of BECs) keeps attacking challenging problems of complexity science while at the same time covering the teaching responsibilities for Computational Science, Cognitive Science, and Computational and Cognitive Biosciences majors in various degree programs of TKK. Towards the end of 2009 COSY moved to the same premises with the rest of BECS in the newly renovated Engineering Physics building in the centre of the Otaniemi campus, which was very much welcomed as it turned out to be very functional and good for the further development of BECS’ and COSY’s future strategies. All the organizational and other strategic developments so far have turned out to be very successful as evidenced by the 2009 international research assessment exercise of all the departments of Aalto University, where BECS and COSY were evaluated as “outstanding” (see: www.becs.tkk.fi/en/research/aalto_rae_2009_becs.pdf).

As the main goal of COSY is excellence in scientific research we focus on understanding the complexity of various physical, biological, cognitive, economical, or social systems, in terms of their structure, function, and response. For this we have adopted trans-disciplinary holistic system level approach combining physical, mathematical, biological, neurocognitive or social science viewpoint with computational analysis, modelling, and simulation. Our research is conducted cohesively in four mutually supportive fields of Models and Methods, Engineered and Artificial Systems, Cognitive and Social Systems, and Computational Health.

In COSY we emphasize our research to be nationally and internationally strongly networked, as evidenced e.g. by the close ties with the Wolfson College of Oxford University in the form of an affiliate research unit. This unit of Computational Complex Systems and Network Research (CCSNR) with its own computing facilities, part-time director, two full-time researchers and a visiting scholar programme for the COSY’s researchers to network with Oxford scientists, continues to collaborate closely with Oxford’s Complex Agent-Based Dynamic Network (CABDyN) cross-departmental research cluster. COSY also cultivates a number of national and international collaborations funded nationally or by EU, as e.g. the FP7 FET Open project ICTeCollective “Harnessing the ICT-enabled Collective Social Behaviour” (http://www.becs.tkk.fi/ictecollective/), which started October 2009 for three years being coordinated by COSY. All these serve also the role of researcher training and bear a lot of scientific fruit, i.e., about 40 scientific publications of which most in high impact factor journals with the average impact factor per journal article of 3.77. as evidence of high research quality. In terms of academic degrees 2009 continued to be a very productive: 23 MSc’s and 4 DSc’s. In summary I would like to end by quoting the COSY’s Scientific Advisory Board report of 2009 (see link: www.becs.tkk.fi/en/research/COSY_SAB-evaluation_2009.pdf): "COSY is at the cutting edge of international science within disciplines that – to our knowledge – are not joined in a single research group anywhere else."

Kimmo Kaski
Professor
2 Personnel

Professors
Kaski Kimmo Professor
Lampinen Jouko Professor
Sams Mikko Academy Professor
Tulkki Jukka Professor

Visiting Professors
Barrio Rafael Prof. (Universidad Nacional Autonoma de Mexico, Mexico)
Kertész Janós Prof. (Technical University of Budapest, Hungary)
Landau David Prof. (University of Georgia, USA)
Rauschecker Josef Prof. (Georgetown University, USA), Finland Distinguished Prof
Rissanen Jorma Prof. (USA)

Adjunct Professors (Docents)
Barrio Rafael Prof. (Universidad Nacional Autonoma de Mexico, Mexico)
Kertész Janós Prof. (Technical University of Budapest, Hungary)
Landau David Prof. (University of Georgia, USA)
Lehtokangas Mikko Docent (Tampere University of Technology)
Mouritsen Ole Prof. (Southern Denmark University, Denmark)
Oresic Matej Docent (VTT Biotechnology)
Parkkinen Jussi Prof. (University of Joensuu)
Räihä Kari-Jouko Prof. (University of Tampere)
San-Miguel Maxi Prof. (Universitat Illes Balears, Spain)
Sutton Adrian Prof. (Imperial College, London, UK)
Tirri Henry Prof. (University of Helsinki)

Administration
Kojonen Senja M.Sc., Project Planning Officer (-7.3.2009)
Lampinen Eeva M.Soc.Sc., Project Coordinator (on leave)
Pyysalo, Laura M.Soc.Sc., Project Planning Officer, M.Sc. (2.2.2010-)
Virolainen Kaija Ph.D., Research Coordinator

Technical Personnel
Aarnio, Timo, System Engineer
Hakala, Mikko M.Sc., System Administrator (7.9.2009-)
Merinen, Jukka, System Engineer
Selonen, Arto Dr.Tech., System Administrator (-22.3.2009)
Senior Researchers
Jääskeläinen Iiro Ph.D., Docent
Linna Riku Ph.D.
Marttinen, Pekka, Ph.D.
Saramäki Jari Ph.D.
Särkkä Simo Ph.D.
Särelä, Jaakko, Ph.D.
Valpola Harri Dr.Tech., Academy Fellow
Vehtari Aki Dr.Tech., Docent, Academy Fellow

Postdocs
Karsai, Marton, Ph.D.
Lukka, Tuomas, Ph.D.
Pan, Raj Kumar, Ph.D.
Segerstahl, Margareta, Ph.D.
Toivonen, Riitta, Ph.D.

Researchers
Balk Marja M.D.
Glerean, Enrico, M.Sc.
Heikkilä, Oskari, M.Sc.
Hyvönen, Jörkki, M.Sc.
Häyrynen, Teppo, M.Sc.
Iniguez, Gerardo, M.Sc.
Jylänki, Pasi, M.Sc.
Jääskeläinen, Pentti, M.Sc.
Kauramäki, Jaakko, M.Sc.
Kettunen, Juho, M.Sc.
Kislyuk, Daniil, M.Sc.
Kivelä, Mikko, M.Sc.
Kovanen, Lauri, M.Sc.
Lehtola, Ville, M.Sc.
Ojanen, Janne, M.Sc.
Parviainen, Elina, M.Sc.
Peltola, Tomi, M.Sc.
Riihimäki, Jaakko, M.Sc.
Toivanen, Miika, M.Sc.
Vanhatalo, Jarno, M.Sc.
Viinikainen, Mikko, M.Sc.
Yli-Krekola, Antti, M.Sc.

Researcher in Oxford University, Oxford, UK
Staniczenko Phillip M.Sc.

Researchers in Harvard Medical School, Boston, USA
Ahveninen Jyrki Ph.D.,
Onnela Jukka-Pekka Dr.Tech.
Nummenmaa, Aapo Dr.Tech.

Research Students
Eiesland, Jon
Heikkilä, Antti
Hänninen, Jarno
Karppinen, Markus
Kontio, Juha
Koskela, Sonja
Kotilainen, Marko
Lahnakoski, Juha
Michelsson, Leif
Niimenen, Jussi
Olsson, Anders
Pennala, Eero
Peura, Heikki
Pietiläinen, Ville
Roine, Ulrika
Rytkönen, Jussi
Räisänen, Paula


3 Boards

3.1 Centre of Excellence Scientific Advisory Board

Board Members

- Professor R Holland Cheng, University of California, Davis, USA
- Professor Alex Hansen, Norwegian University of Science and Technology, Norway
- Professor George R. Mangun, University of California, Davis, USA

Observers

- Professor Ulla Ruotsalainen, Tampere University of Technology (2006-7)
- Research Professor Tuija Pulkkinen, Finnish Meteorological Institute (2008-)
- Science Adviser Pasi Sihvonen, Academy of Finland, Programme Unit
- Science Adviser Anu Justusin, Academy of Finland (2009-)
- Senior Science Adviser Pentti Pulkkinen, Academy of Finland (2006-7)
- Science Adviser Vesa Siivola, Academy of Finland (2008)
- Vicerector Outi Krause, Helsinki University of Technology
- Technology Manager Erkki Hietanen, Finnish Funding Agency for Technology and Innovation (Tekes), Helsinki

3.2 Internal Research Board “Oldies”

- Jääskeläinen Iiro Ph.D., Docent
- Hakala, Mikko M.Sc.
- Kaski Kimmo Professor (Chairman)
- Kojonen Senja M.Sc.
- Lampinen Eeva M.Soc.Sc.
- Lampinen Jouko Professor
- Linna Riku Ph.D.
- Pyysalo, Laura M.Soc.Sc.
- Sams Mikko Professor
- Saramäki Jari Ph.D.
- Särkkä Simo Ph.D.
- Tulkki Jukka Professor
- Valpola Harri Dr.Tech., Docent
- Vehtari Aki Dr.Tech., Docent
- Virolainen Kaija Ph.D.
4 Teaching

Degree programmes and major subjects

Courses spring 2009
- S-114.1327 Physics III (EST) (6 cr)
- S-114.1427 Modern Physics: Computational Virtual Laboratory (Sf) (2 cr)
- S-114.2240 Seminar on Computational Engineering (3 cr) V
- S-114.2510 Computational Systems Biology (5 cr)
- S-114.3155 Business Game (3 cr) P
- S-114.4202 Special Course in Computational Engineering II (3-6 cr) P V
- S-114.4220 Research Seminar on Computational Science (3 cr) P V
- S-114.4610 Special Course in Bayesian Modelling (1-8 cr) P V
- S-114.4762 Systemic cognitive neuroscience (2 cr) L

Autumn 2009
- S-114.1100 Computational Science (5 cr)
- S-114.1310 Introduction to Modelling and Information Theory (3 cr)
- S-114.2500 Basics for Biosystems of the Cell (5 cr)
- S-114.2601 Introduction to Bayesian Modelling (5 cr) P
- S-114.3200 Special course on computational engineering (6 cr)

Courses that can be taken any time
- S-114.3215 Special Project in Computational Engineering (3-8 cr)
- S-114.3520 Special Project in Computational Systems Biology (3-7 cr)
- S-114.4220 Research Seminar on Computational Science (3-6 cr) P V
- S-114.4230 Individual Studies on Computational Engineering (1-6 cr) P V
- S-114.4612 Special course in Bayesian modelling 2 (1-8 cr) L V
- S-114.4771 Special Project in Cognitive Science and Technology (3-7 cr) P V
- S-114.4772 Individual Studies in Communication and Cognition (1-9 cr) P

Abbreviations:
L & P: The course can be taken in Bachelor, Masters or Doctoral level studies
V: A course with varying content

For more information see:
Study Programme, Helsinki University of Technology
The study www-page: http://www.becs.tkk.fi/fi/opinnot/
5 Theses

Doctor of Science / Philosophy

- Heimo, Tapio (Complex networks and spectral methods: an econophysics approach to equity markets.)
- Jouhten, Paula (Metabolic modelling and 13C flux analysis- application to biotechnologically important yeasts and a fungus.)
- Laksameethanasan, Danai (Three-Dimensional Reconstruction Methods for Micro-Rotation Fluorescence Microscopy.)
- Toivonen, Riitta (Social networks: Modeling structure and dynamics.)

M.Sc. - Diplomas

- Anttalainen, Sini (Interactions between fullerols and DNA/RNA oligonucleotides.)
- Heini, Kari (Changes in the activation of human auditory cortex during visual speech perception and soundless vowel production: an fMRI study.)
- Helle, Liisa (Synchronous neural interactions as a biomarker: Experimental evaluation of a clinical MEG data analysis method.)
- Jalava, Antti (Detection of task-related neural networks with dynamic imaging of coherent sources.)
- Kangas, Antti J. (Automated analysis of serum 1H NMR spectra.)
- Kivelä, Mikko (A network perspective on the genetic population struture of seagrass Posidonia oceanica.)
- Kovanen, Lauri (The structure and dynamics of a large-scale complex social network.)
- Kumpula, Hanna (Comparing Three Motor Threshold Estimation Methods Using Simulation and Navigated Transcranial Magnetic Stimulation.)
- Lehtomäki, Matti (Dynaamisten prosessimallien parametrien viritysmenetelmä.)
- Luomahaara, Juho (Field-tolerant SQUID sensors for a hybrid MEG-MRI system.)
- Metsomaa, Johanna (Locating electroencephalographic sources induced by transcranial magnetic stimulation.)
- Niskasaari, Arttu (Outsourcing usability evaluation in agile software.)
- Peltola, Tomi (Multivariate exploratory analysis of the habitual diets of patients with type 1 diabetes.)
- Pennala, Eero (Bayesian detection of genetic associations for metabolic syndrome.)
- Pousi, Jouni (Decision analytical approach to effects-based operations.)
- Saari, Teppo-Heikki (Machinery safety risk assessment of a metal packaging company.)
- Savunen, Tapio (Application of the Cooperative Game Theory to Global Strategic Alliances.)
- Sipponen, Sini (Automatic sleep scoring from frontal electroencephalogram.)
- Vesananen, Panu (Compressed sensing in parallel magnetic resonance imaging.)
- Vesterlund, Jenny (Light adaptation in mouse cones.)
- Virkkala, Ville (Development of an Epileptiform Spike Detector.)
- Virtanen, Seppo (Continuous Impedance Measurement as a Signal Quality Indicator in Electroencephalography.)
- Vuorio, Ville (Rajoitetun kulman hammasröntgentomografiakuvien jälkikäsittely.)
The general aim of COSY is to conduct transdisciplinary research on complex systems around and affecting us by using holistic system-level research paradigm and by developing new tools for studying them. In order to understand the complexity of various natural, technological, and societal systems holistic system-level research approach is needed. We have taken up the challenge to study structural and functional properties of systems from multidisciplinary perspective by using computational data analysis, modelling, and simulations.

The research of COSY (Error! reference source not found.) is conducted by joining the expertise of its researchers in physical, biological, cognitive, and computational sciences with loose grouping into four focus areas.

The main role of the Models and Methods research line is to facilitate the research of the other groups of the COSY. The focus is both on "fundamental" as well as on "applied" research. The former comprises theoretical and numerical work on mathematical and physical models of complex systems with one of the main focuses being on complex networks and agent-based models, and complex dynamics and statistical physics. In the latter, the focus is on computational tools and methods required for analysing and understanding experimental data of, for example brain signals and public health data.

In Engineering and Artificial Systems the research focus is twofold, on material based engineered nanosystems and on modelling of learning and perception. In nanosystems the goal is to understand the fundamental behaviour of (solid, soft or biological) materials and devices that show intrinsic complex phenomena such as pattern formation, self-organisation and self-assembly. These nanoscale systems are well-suited for computational modelling studies, which form the basis for applying them in nanoscale bioinformatics, biomedical analysis and in imaging systems. In modelling of learning and perception the research is based on computational models of various cognitive functions of humans, including learning, perception, and communication. The results are applied in computer vision and object recognition, and in robotics to study task-driven modelling of cognitive functions from computational neuroscience perspective.

In Cognitive and Social Systems, the research on cognition focuses on analysing and combining data obtained using complementary non-invasive neuro-imaging methods, to disclose dynamic neuronal interactions within and between brain areas. The aim is to
develop an integrated computational model to predict how those interactions give rise to emotion-motivated (goal-directed) audio-visual selective attention. In Social systems research the structure and dynamics of social networks is analyzed and modelled based on complex networks and agent based approaches.

In **Computational Systems Biology and Computational Health**, the focus is to understand biological systems at various levels (molecular, cellular, tissue, organ and individual) and national health issues through computational modelling and information theoretic data analysis methods, using data gathered with bio-spectroscopic methods (e.g. NMR), genome-wide studies, and data on national health records.

![Diagram](image)

**Figure 1** The research is conducted in four mutually supportive fields
Figure 2 Centre of Excellence COSY, the total funding for the year 2009

Figure 3 Master of Science and Doctor of Philosophy Degrees
Figure 4 Publications

Figure 5 Impact factor of the refereed publications
In recent years we have seen much progress in the analysis, modelling, and theoretical studies of complex systems, with the result that seemingly very different systems can be fruitfully approached with similar methods, and share sometimes similar characteristics. These findings illustrate the interplay between the different approaches, as well as the benefits of interdisciplinary work on complex systems. As an example, the existence of unexpectedly broad connectivity distributions in complex networks was originally discovered by statistical analysis of data on the World Wide Web. Then, it was theoretically and though simulations shown to result from certain types of network growth processes which also take place in several biological and social systems. Another illustrative example of a successful cross-disciplinary framework is Bayesian statistical modelling, which has during the recent years found applications across a wide range of disciplines ranging from engineering to neuroscience, and it is rapidly becoming the standard approach in statistical modelling.

The synergies of approaching complex systems from several perspectives are quite obvious and evident. In particular, theoretically oriented development of models and methods largely benefits from collaboration with researchers who have detailed knowledge and experience on particular complex systems, such as the human brain or various biomolecular systems; likewise, the researchers working on these systems are best served by modelling work which is driven by their needs. The Models and Methods group of the CoE focuses on both theoretically oriented work as well as empirical research. Theoretical studies are related to statistical and mathematical models of complex systems, as well as developing "generic" methods for complex systems research. The empirical research at Models and Methods focuses on developing computational tools and methods and applying them on various types of empirical data, such as electronic databases of mobile telephone communication, healthcare registry data, data on industrial processes, and spatial data related to epidemiology.
6.1.1 Complex Networks and Agent-Based Models

The network approach to complex systems has turned out to be very successful during the last years. It has revealed general principles applicable to a large number of systems from a wide range of disciplines -- there are surprising similarities between networks of protein interactions, the Internet, economic systems and large-scale social networks. In general, complex systems consist of large numbers of interacting elements and have highly non-trivial interaction structures. A system’s behaviour is then determined by the properties and dynamics of the elements as well as the interaction structure. The main strength of the complex networks approach is its inherent ability to provide a simplified view of this complicated picture, which is achieved by disregarding non-essential features. However, some information is always lost in such simplifications: one of the current trends is to limit this loss by including additional information about e.g. interaction strengths to the complex networks framework.

In the network approach, interacting elements are represented as vertices and their interactions by edges. Studies of network characteristics have produced novel findings such as the small-world property, the ubiquity of networks with broad degree distributions (the degree of a vertex is simply the number of connections it has), and the frequent appearance of high clustering and hierarchical structures. In other words, many statistical characteristics have been observed to be universal, i.e. similar in a large number of very different networks. Modern-day electronic databases and computational tools have been of especial importance to the development of this framework.

Lately, it has been realized that the simplest approximation, where edges either exist or not, has to be extended for a deeper understanding of the function and dynamics of complex networks. First, the interaction strengths can be taken into account in the form of edge weights – this additional degree of freedom provides deeper insight into the structural properties of networks. Second, in many cases, edges are not static: there is dynamics on multiple time scales, from very fast processes of link activation-deactivation to slower processes of dynamic rearrangements of entire networks. Both of these aspects (interaction strengths, edge dynamics) are inherently linked to the mesoscopic structure of complex networks – structure beyond the scale of single vertices or their immediate neighbourhoods.

Such structure is typified by communities, which are sets of nodes with dense and strong internal connections, loosely connected to the rest of the network. Community structure is typically nested – smaller communities reside inside larger ones – and has important consequences on any dynamic processes taking place on networks. The recent activities of the Networks group are related to the above issues: our focus has been on developing the theoretical and methodological framework of weighted complex networks,
initiating studies of edge dynamics and their relationship to network structure, and developing and assessing methods for detecting community structure on multiple scales.

As discussed above, in the framework of weighted complex networks, the interaction strengths of a complex system are taken into account. This is usually achieved by assigning a scalar value to each edge representing the interaction strength. As an example, in the network of world trade, vertices represent countries, an edge exists between two countries if there is mutual trade, and the weight of this edge represents e.g. the total annual trade volume – we have investigated several aspects of this interaction system using weighted network methodology (Battaharya et al, J. Stat. Mech. P02002 (2008)). Likewise, in social networks, the strengths of social ties are readily taken into account as edge weights. Incorporating this additional degree of freedom into the network picture evidently gives rise to new questions: how to measure and characterize the correlations between weights and topology? Are the weights distributed differently in different types of networks? How do the weights affect dynamic processes taking place on networks? How do the weights relate to mesoscopic properties, such as community structure?

In order to answer these questions, we have investigated several empirical weighted networks, and simultaneously developed methods for weighted network analysis. Some empirical data sets are inherently weighted networks – consider, e.g., the above-mentioned world trade network, or a large social network reconstructed from mobile telephone call records, where the total amount of time spent on the phone between two persons is a natural proxy for the tie strength. On the other hand, some systems where all elements interact with each other to a varying extent may also be recast as networks e.g. by progressively filtering out interactions of negligible strength. Such systems include stock markets, where all information is contained in correlation matrices computed from stock price time series, or genetic relationships between living entities. The latter case has been studied within the EU FP6 NEST-Pathfinder project EDEN, where the genetic relationships, evolutionary patterns, and ecological diversity of Mediterranean endangered marine plants are studied with network methods, in collaboration with institutions from Spain, Portugal and Germany. Here one of the key objectives is to detect clusters of genetically similar samples and understand their relationship with the underlying geography. In conjunction, we are developing software which allows biologists to easily utilize network-related data analysis techniques in studies of genetic relationships.

As mentioned above, communities and modules, i.e. sets of nodes with dense internal connections and higher-than-average link weights, are abundant in complex networks, and detecting and understanding such structure is one of the most important research trends in today’s network science. We have approached this problem from the methodological perspective, developing algorithms (Kumpula et al, Phys. Rev. E 79, 026109 (2008)) and mathematical methods (Heimo et al, Physica A 386, 5930 (2008), Heimo et al, J. Stat.
Mech. P08007 (2008)), as well as studied the effects of such structure on dynamic processes (Toivonen et al, Phys. Rev. E 79, 016109 (2009)). For the algorithms and methods, our main focus has been on extracting hierarchical, nested community structures from weighted networks with multilevel methods, allowing us to investigate the studied systems with multiple resolutions. We have also focused on methods which allow studies of very dense weighted networks, in practice systems described by full interaction strength matrices. Furthermore, we have also taken the first steps towards understanding the dynamics of such structures (Heimo et al, Physica A 388, 145 (2009)).
**6.1.2 Complex Dynamics and Statistical Physics**

*Polymer dynamics*

The group’s research is motivated by analysis of experiments on structurally and dynamically complex systems in biology. Also non-physical complex structures, where unrestricted connectivity induces complex behaviour, are studied. Many biologically relevant structures and processes are characterised by their elasticity and rheology, whose interplay results in highly complex dynamics. In addition, the investigated structures, like the cytoskeleton, are heterogeneous, which paradoxically places a requirement of complete understanding of the object’s mechanics in order to be able to interpret measurements correctly. Hence, the only way to find the correct structure and mechanics of the object is to construct a computational model that gives the experimentally observed behaviour.

Our computational models are typically based on coarse-grained methods, such as stochastic rotation dynamics (SRD). In our hybrid algorithm the object under study follows detailed molecular dynamics while the solvent is modelled using SRD. Hence, molecular details of the solvent are not included. The coarse-grained solvent acts as a momentum conserving heat bath which can support hydrodynamic modes. Thus the method is ideal for investigating systems characterised by rheology and elasticity.

---

**No-slip**

![No-slip Diagram](image)

*Figure 6 Stretched wormlike DNA-chain*
The first necessary step of characterising computationally the basic building elements of biological structures has been done. They are typically describable with various polymer models, which then link to form more complex structures. The research has then proceeded from fundamental characterisation of biopolymers (e.g. DNA, RNA, and proteins) in biologically relevant circumstances towards processes involving complex dynamics and geometries. The ubiquitous process of biopolymer transport, or translocation, through nano-scale pores is a prototype example of a case where fairly simple constraints induce complex dynamics. Typically, for example in the protein import into intra-cellular compartments, such as mitochondria, chloroplasts, and peroxisomes, the translocation is aided by an electric pore potential. We have made a critical study of computational methods used in this problem. We have shown that forced translocation is distinctly a non-equilibrium process even at pore potentials which barely induce translocation. We have introduced a phenomenological theory describing this process. Our results put the theory for biological translocation processes into a new perspective. Most notably, our results show that there exists no universal scaling law relating the translocation time to the polymer length, which is in clear contrast to several claims based on computer simulations using less realistic dynamics. This has significant bearing on the design of experimental setups for DNA sequence decoding.

The research focus has shifted towards developing computational models to encompass increasingly complex structures. An implementation of a model for a polymer ejecting a viral capsid is underway. High-quality experimental data on lipid bilayer structures and proteins will be available via collaboration with Helsinki Biophysics and Biomembrane group, and computational models for them will be implemented.

Collaboration has been launched with the Center for simulational physics, University of Georgia in order to use the so-called Wang-Landau sampling in the context of protein structures and the capsid ejection.

Figure 7  A snapshot from the simulation of a polymer translocation through a pore in a wall

Collaborators
University of Bonn, Germany
Dr. Joachim Kappler
Helsinki Biophysics and Biomembrane group
Prof. Paavo Kinnunen
6.1.3 Statistical Brain Signal Analysis

The expertise of both Bayesian Methodology group and Cognitive Science and Technology group meet in the statistical brain signal analysis project. The work is done in collaboration with Massachusetts General Hospital–Harvard Medical School NMR Center and the Department of Signal Processing of Tampere University of Technology.

The overall aim of this project is to apply the methods of Bayesian data-analysis to the study of cognitive brain functions as revealed by MEG, EEG, and functional Magnetic Resonance Imaging (fMRI). We employ a variety of state-of-the-art estimation techniques from Markov chain Monte Carlo (MCMC) to Variational Bayesian (VB) methods.

Localising the neural currents indicating brain activity based on non-invasive magnetoencephalographic (MEG) and electroencephalographic (EEG) measurements (i.e., solving the electromagnetic inverse problem) is most naturally formulated in probabilistic terms and thus becomes a problem of statistical inference. Because of the ill-posedness of the inverse problem, reliable inference cannot be made relying on the data only. Some additional a priori information must be provided in order to obtain sensible results, motivating a Bayesian treatment of the problem.

Another focus of the research is on developing data-analysis techniques for combining MEG and fMRI. The rationale behind this is that MEG has excellent temporal resolution, but obtaining inverse estimates with high spatial specificity is hampered by the possibility of several distinct current patterns producing very similar MEG measurements. On the other hand, conventional fMRI provides direct spatial information about the possible locations of brain activity, but with limited temporal resolution. As a practical application, we have begun to implement our advances in these methods in 2009 in our ongoing studies of top-down modulation of human auditory system during selective attention tasks.

As a new emerging research area where brain signal analysis method development is inherently useful, we moved strongly towards using naturalistic stimuli in functional magnetic resonance imaging to study phenomena such as perceptual processing under ecologically valid stimulus settings, neural basis of emotions, and social cognition. Here, we have utilized blind analysis methods such as inter-subject correlation (ISC) and independent component analysis (ICA), but are rapidly moving towards developing methods that allow more refined analysis of the highly complex data that is gathered during e.g. watching of movies, such as Bayesian hierarchical models where a priori information based on self-reports of the subjects as well as detailed annotation of sensory and cognitive

Senior researchers
Iiro P. Jääskeläinen
Jouko Lampinen
Mikko Sams
Aki Vehtari

Researchers
Toni Auranen
Aapo Nummenmaa

Project homepage: http://www.lce.hut.fi/research/mm/brain/
aspects of the movie stimuli.

Figure 8 A schematic illustration of the Variational Bayesian algorithm iterations in the MEG source localization procedure. Instead of several small current sources, only a few prominent sources pop up as a result of the algorithm.

Collaborators
Massachusetts General Hospital– Harvard Medical School, USA
  Dr. John W. Belliveau
  Dr. Matti S. Hämäläinen
  Dr. Aapo Nummenmaa

Tampere University of Technology
  Dr. Jussi Tohka
Modern technology research is building novel artificial systems. In nanotechnology this emphasizes the need to understand the fundamental behaviour of materials fields and devices, which show intrinsic complex phenomena such as pattern formation, self-organisation and self-assembly. In the area of information technology, we develop computational models of cognitive functions, such as learning and perception, which are central issues in many research topics throughout the COSY. We apply the results in computer vision and object recognition, and in robotics to study task-driven modelling of cognitive functions from computational neuroscience perspective.
6.2.1 Engineered Nanosystems

The research of micro- and nanoelectronic materials, photonics and devices is getting a wider interface with problems of molecular and cell biology and medicine. This offers a manifold of new challenges for multidisciplinary theoretical research and computational science. At micro- and nanoscale the interaction of semiconductor, polymer and metallic surfaces with molecular level biosystems and the modulation of this interaction with microscopic voltage probes, light or chemical agents will be subject of extending research in the next years.

Information storage and communication systems utilizing quantum and all-optical devices are areas where nanomaterials and their technological applications are being worked out. In these areas we have continued to work on photonics applications. A new project has been started on developing very high efficiency light emitting devices that can be applied for white light luminaire as well as for specific thermophotonic devices.

In nonlinear materials we have studied carrier dynamics in quantum dots excited simultaneously by terahertz radiation from a free electron laser and an Ar-ion laser. The theoretical model and simulations are used to analyze recent experiments at UCSB. This work involves also collaboration with University of Tokyo. As a highlight of our work in this area we have proposed a new radiation based cooling mechanism of quantum dot excitons.

Recently started project on photonic biomorphic neural circuits has been continued. In this research area we work on stochastic properties of thermal and coherent photon fields. The photon bunching in partially coherent light is analyzed using dynamic quantum kinetic models in order to develop a quantum optical model of the network eye.

Project homepage: http://www.lce.hut.fi/research/eas/nanosystems/
Modelling high efficiency light emitters for general lighting

Solid state lighting based on wide bandgap semiconductors and LEDs is expected to provide a viable way to high efficiency (up to 70-80 %) lighting solutions in the next 5-10 years. Lighting is the largest single user of electric energy with a 20 % share of global electricity consumption and large electrical energy savings will be possible using LED based lighting solutions. Currently, however, the performance of LEDs is still insufficient for use in general lighting applications and further advances are required. The research of this project is conducted as a part of the 5-year research program, 'High Efficiency Solid State Lighting Enabled by New Technologies' (HighLight), started in 2008 and lead by Prof. Harri Lipsanen, Department of Micro and Nanosciences. The HighLight program is a part of the Multidisciplinary Institute of Digitalisation and Energy (MIDE) of TKK and concentrates on the development of high efficiency LED structures for general illumination.

A part of the HighLight project will be dedicated for the study of novel nanometer scale light emitting structures (quantum dots and wires) and novel semiconductor/air interfaces for optimal photon extraction. This includes studies of photon extraction by patterning the semiconductor surfaces by nanoparticles or photonic crystals.

This project also studies the thermodynamics of light emission in semiconductors and the effect of the materials and device geometries on the efficiency of LEDs. This far the project has concentrated on studying the differences of conventional LED structures and new lateral LED geometries, as well as on studying the temperature dependence of the efficiency of LEDs and the thermodynamics of optically coupled LED structures. The modeling of LEDs and other light emitting devices is based on complex groups of nonlinear differential equations, which include the semiconductor equations, transfer equation for photons and heat, the interaction between photons and matter as well as models for the dielectric optical cavities of LEDs. The phenomena described by the models include the current, heat and photon transfer in the devices and provide valuable insight in the operation and loss mechanisms of LEDs and light emission in general. Special interest in the analysis has been paid in the temperature dependence of the light emission properties of the LEDs.

Practical applications of the models include new LED geometries and photonic heat pumps. The photonic heat pumps are devices where heat is transferred by photons instead of the more conventional working fluids of mechanical heat pumps or charge carriers of Peltier elements. The photonic heat pumps show promise for exceeding the performance of conventional solid state heat pumps based on Peltier effect. At best the structures may even compete with compressor based heat pumps on special applications.
Figure 9  A schematic picture of the band diagram of a double heterojunction light emitting diode illustrating the electron and hole transport, phonon absorption and light generation in the active region. The electrons (holes) flowing to the active region through the n-type (p-type) semiconductor absorb energy from the phonons as they climb over the potential gradients. When the electrons and holes recombine the absorbed heat contributes to the energy of the emitted photon. The black and white color gradient describes the electron distribution in the structure; black corresponds to a filled electron state and white to an empty electron state. The small curly arrows represent phonons and the large curly arrows represent photons.

Collaborators
Department of Micro and Nanosciences, TKK
Prof. Harri Lipsanen
Quantum trajectory approach to photon counting

Quantum trajectory approach to photon counting

Usually photon detection statistics of the electro-magnetic field are calculated assuming that the field remains unchanged by the photon measurement process. For high intensity fields the changes may be neglected but for low intensity fields the measurement back action to the electro-magnetic field must be taken into account. An appropriate interpretation of this phenomenon is related to the fundamental quantum measurement theory.

The instantaneous changes in quantum systems are modelled using the quantum jump superoperators. The quantum jumps produce interesting phenomena. For example with selected initial conditions for the electro-magnetic field an absorption process can increase the expectation value of the number of the photons in the field.

We have modelled the photon subtraction using the quantum trajectory theory and derived operators for absorption of exactly one photon and at least one photon based on the Srinivas and Davies (SD) model [J. Mod. Optic. 28, 981, 1981]. These operators correspond to experimental setups with resolving and non-resolving detectors, respectively. Calculated coincidence photon counting probabilities for the Fock state, thermal field, and coherent field are shown in Fig. 1. Furthermore, we have shown how the operators are applied consistently within the quantum trajectory theory.

Researchers
Teppo Häyrynen
Jani Oksanen
Jukka Tulkki

Figure 10 The coincidence probabilities of counting photons
Modelling of cognitive functions is central issue in many research topics in the COSY – both to model the human cognitive functions, and to build artificial systems with those capabilities. In general perception can be seen as a signal processing or a state estimation problem. In the signal processing view, the sensory signals are processed in the system in order to detect the signal from noise, and to make classification and recognition based on the signal. Another view is that the system maintains a state space representation of the outside world, and the sensory signals are used to update the state. The signal processing view leads to bottom up, or data driven, processing, possibly with top-down feedback from context modulating the classifier operation. The state estimation view is a top-down, or model driven, scheme, where the current system state produces predictions for the sensory signals, and the prediction residual is a novelty signal used to update the system state.

The signal processing view is appropriate for many machine vision applications, like quality inspection, identification and limited surveillance applications. For generic perception skills, it is not clear how some required properties can be implemented in this view. These include fusing the information from several sensors, integrating different cues from one sensor modality, integrating temporal cues, and the specific role of context and background information in the processing.

In the state estimation view there is a latent representation for the world, giving prediction to the sensory signals. Thus all the sensory signals or cues that are predicted from a state variable can be readily used to update the variable. Mathematically the uncertainty in the state estimate and predictions can be represented as probability distributions, leading to Bayesian inference. In this scheme all the previously learnt or perceived information together with all the context information in the current task form the prior probabilities for the state variables and sensory signal predictions, and the Bayes’ rule is used to update the state after the sensory signal is observed.

From the engineering point of view, the Bayesian state space approach brings together classification, dynamic state estimation and inverse modelling as different parts of the perception task. There are also evidentially supported theories for modelling the brain functions as Bayesian inference (e.g. see the works of David Mumford and Karl Friston).

In our group we are developing object recognition and scene analysis methods based on Bayesian inference approach. Often in top-down object recognition a major problem is the weak influence of the data to the process. We are using Monte Carlo methods for the latent state representation, so that the recognition is done by sampling from the complex posterior distributions determined by the prior probabilities (from the context) and the likelihood function linking the state variables to the sensory signals. We have been developing sampling methods where the sensory signals are used efficiently in the proposal distributions. In the following we review results of Bayesian object matching.
**Bayesian object matching**

Object recognition and scene analysis are inherently ill-posed problems, as the visual information projected on the image plane (camera or retina) is not sufficient for inferring the 3D world characteristics. Thus some kind of prior knowledge of the world and the objects must be included in the process. Probability theory (i.e., Bayesian inference) provides one approach, which is theoretically consistent, and applies to recognition of objects given the image, as well as to learning of the world characteristics given a set of known samples.

We have been developing an object and scene analysis approach based on Bayesian inference. The feature part of the system is based on Gabor filters, which resemble the simple cells on primary visual cortex. On these primitive features, the system learns the variability of shapes of known objects (such as faces) and also the variability of individual details (such as the corner of the left eye). For recognizing an unknown object in a novel image, the object is modelled by the learned shape model and individual random effects, and the matching of the objects is carried out by evaluating the posterior distribution of all the unknown model parameters, including the feature positions on the image. This replaces the search, or model fitting, in traditional error-minimization techniques. The developed approach is rather generic, based directly on the probability theory with little ad hoc elements, which makes it easy to extend the model. For example, a difficult problem with flexible shape models (such as elastic graph matching, which represent state-of-the-art in face recognition) is partial occlusion of the object by other objects.

![Sequential feature matching.](image)

Figure 11 Sequential feature matching. The black circles mark the drawn locations of the current feature, while the green circles are the previously drawn features. The shape (yellow lines) represent the mean of the shape prior.

We have developed an occlusion model yielding joint estimation of the visibility and the position of the features, which can handle even serious occlusions (see Figure 11). We have also developed an efficient MC-method, based on sequential Monte Carlo sampling that requires no initialization and can handle any number of visible features. The sampling roughly corresponds to matching the features sequentially, starting from the most significant features in each image, automatically without any predetermined order. Special novelty in the system is a near-optimal proposal distribution for the feature positions, which takes into account both the likelihood (‘where the feature is seen on the image’) and the shape prior (‘where the feature would be given the other features’). Figure 11 shows an example of the sequential matching process and Figure 12 illustrates matching when the target objects are occluded.

Figure 12 Matching in the presence of occlusion. Even though the target objects are heavily occluded, the system is able to find the approximate locations of the features.
Steerability properties of Gabor filters

Gabor filters are information-theoretically optimal oriented bandpass filters which have been traditionally used in pattern recognition as a generic framework for the representation of visual images. Gabor-based features are widely used in face recognition, for example. Neurological studies have found Gabor-type structures on the visual cortex of mammals. This fact suggests that the Gabor representation is an efficient one in pattern recognition tasks.

We have derived analytical steering equations for Gabor filters, which enable Gabor filters to be used as approximately steerable filters, whose responses can be interpolated to arbitrary orientation, eliminating time-consuming recomputation of the Gabor transform with a rotated image. Some families of steerable filters are quite close to Gabor filters in terms of impulse responses, and the steering performance of Gabor filters can be understood via this connection.

Steerability can be used in object matching for explaining variation in features due to plane rotations. We have successfully applied Population Monte Carlo methods for rotation-invariant matching problems, where steerability can also be used for choosing efficient proposal distributions for the rotation parameter, leading to faster convergence.

Figure 13 Probabilistic object matching without and with filter steering, with their average feature similarity scores shown on top of the images. Steering corrects the effect of rotation and the similarity scores remain almost constant.
Finding novel objects and object classes

We have built a probabilistic model that aims in locating instances of a common object, appearing in a set of unannotated images. The approach is sequential; the images are processed one at a time, and each matched instance is used as training data for the upcoming images. The used object representation is sparse, consisting of grid of nodes, which are matched in a novel image. Simple automatism is used to select the nodes in the first image. Along the sequence, the system learns the representation of the object, i.e. typical appearances of the nodes with certain arrangement. Only the nodes that correspond with the training nodes should be associated with the object, which is an issue that we have lately been studied. The probability distribution of the nodes is sampled with Sequential Monte Carlo methods, which we also have revised lately.

Figure 14 The matching results of a sequence of 30 images, containing a dog. Top row shows the first three images of the sequence, and bottom row the last three. The means of the SMC samples are marked with dots, and the sizes of the dots are proportional to the prior association probabilities and the colours to the posterior association probabilities, so that the greener the dot, the higher the probability. On the right, the evaluation of the prior association probabilities are illustrated.
6.2.3 Computational Neuroscience

The computational neuroscience group in LCE studies the system-level organization of the brain. In the brain, there are several interacting subsystems, which work in concert and each contribute to generation and adaptation of behaviour. In order to understand the brain, our group is building computational models of these subsystems and studying the complex, emergent behaviour and learning of an agent, which interacts with its environment. This type of research is called embedded computational neuroscience and it requires a body and environment to interact with. To this end, we have used a physics simulator platform. In other words, we have worked on simulated robots but in the future we also aim at verifying the results with real robotic platforms. ZenRobotics Ltd., a spin-off company of the group, already applies the methods for real robots.

Overview of the brain architecture – an evolutionary perspective

During evolution, the brain has always been part of a complete autonomous system. We are roughly following the evolutionary path of mammalian brain development and that is why our first embodied model—a complete brain which controls an autonomous robot—was cerebellar motor control. Cerebellum is an evolutionarily old system and is shared by all vertebrates and is critically involved in motor control. However, it is also known that cerebellum is involved in sensory processing, sensorimotor integration and cognitive functions. Algorithmically, a simple description of cerebellum is that it is a predictor. We have shown how a simple predictor can assist in motor control and it is also easy to see how a predictor can assist in the other tasks, in which cerebellum is known to be involved.

Our development of the computational models for different parts of the brain is by no means strictly serial. Rather, we are developing and testing computational models of various parts of the brain before they get integrated in autonomous agents. The point in building a complete autonomous agent is that we get a better intuition about what kind of processing is needed by the already existing integrated components in order to improve motor performance and ability to tackle more complex environments. We can then tune the hypotheses about the computational role of different parts of the mammalian brain.

Apart from the cerebellar model, the main topics of our research have so far been the basal ganglia and the mammalian neocortex. Basal ganglia are thought to assist in selection of behaviours and learning through trial and error. Evolution has determined a set of fixed reflexes and action patterns for an animal. Now, the basal ganglia can learn similar patterns. Thus, they make the agent adaptive to an unknown world.

As opposed to cerebellum, neocortex appeared quite late in evolution and is shared by modern mammals. Neocortex is the most complex part of the brain and tremendously enlarged in humans. It is the site of high-level cognition, consciousness and imagination.
Dorsal cortex, the evolutionary precursor of neocortex is much older and simpler, though. It seems that one of the first tasks the precursor of neocortex solved was development of behaviourally meaningful representations. As an example, consider a balancing robot which is riding an uneven terrain and has cameras enabling depth vision—in principle; it is by no means a trivial task to extract depth information from the images of two cameras. We are investigating how motor signals can bias the development of perceptual systems and dynamic selection of useful information (selective attention) such that perception will be optimized for the behavioural needs of motor control.

We have already started to integrate the models of different brain modules. We have noticed that the interplay between the cerebellum and the basal ganglia enhances learning of both of the modules. We have also noticed how crucial it is for the neocortex to be able to represent different contexts for the cerebellum.

Other systems that we plan to incorporate in the model later include the hippocampal formation. This module appears to have developed to assist navigation and is able to compress, store and replay sequences of events.

Although the different modules of the mammalian brain seem to have evolved to serve the needs of basic motor control, these mechanisms have later been adopted by higher-level cognition. For instance, when we plan, we in a sense navigate through options and select promising paths of thinking. This can be considered as internalised navigation where basal ganglia help us make choices and hippocampal formation enables us to remember the paths of thinking. It is easier to study and understand navigation, manipulation and sensory associations than planning, reasoning and symbolic language, but the same underlying mechanisms are at work.

**Cerebellar learning for motor control**

The cerebellum is responsible for timing, fine-tuning and coordinating the motor system. By learning in a self-supervised fashion from error signals generated by other parts of the brain and body, the cerebellum is able to rapidly execute and accurately time motor actions in response to external stimuli.

The learning algorithm executed by the cerebellum is efficient and simple: if a reflex is triggered in response to an event, the system will associate the action of the reflex with the system states that preceded the event. The next time a similar state is observed, the system will anticipate the reflex by performing the reflex action beforehand. With suitably chosen reflexes, the cerebellum learns to be a stable controller that can, for instance, keep a dynamically balanced robot upright.

One of the main attractions of the cerebellar model of control is its robustness: the system can quickly learn to respond to new conditions, and can learn to anticipate changes in the external world that place demands on the motor system (for example, knowing that a heavy weight will shortly be placed in one’s hands, a person will automatically prepare by assuming a more solid posture). The cerebellar algorithm is also able to make use of any contextual data from the rest of the brain that happens to be available.

Our work concerns the application of the cerebellar control model into robotics using a simulation environment; the ability of the cerebellar controller to take advantage of extraneous inputs for adaptation and the mathematical aspects of the cerebellar controller itself.
Figure 15 shows a simple simulated wheeled robot using the cerebellar algorithm for stabilizing itself. The robot is able to stay upright even when its sensory inputs (tilt, velocity etc.) are delayed. The robot has thus learned to anticipate its future state with the help of a reflex telling it when it is or was about to fall over.

The cerebellar algorithm was also proven to be able to coordinate a system with several degrees of freedom. The goal of the system was to keep the multi-jointed robot arm at a given position (Figure 16). The segments interact and righting one segment will cause the others to experience more force and can easily lead to unstable states. By taking into account the positions of all joints and anticipating the motion of the others the cerebellum learned to compensate for them proactively.

Our ongoing cerebellar research focuses on contextual inputs. The small images in Figure 15 show an example of changed dynamics. When the heavy weight the robot is carrying moves in vertical direction, the dynamics of the system change, and the controller needs to account for the changes. We are now investigating ways to convey information about the changed context to the cerebellum.

Figure 16 A three-joint arm (black) where the joints have learned to coordinate with each other by predicting each other’s effects on themselves. The extra boxes are animated bar graphs that visualize various dynamic variables.
Model of neocortex

As its name suggests, neocortex has evolved relatively recently, some time after mammalian lineage departed from reptiles. The neocortex has expanded the most during evolution and with its numerous folds and gyri is the largest structure in the human brain. The neocortex processes inputs from all the senses and is the seat of high-level cognitive functions such as decision making, imagination, planning and consciousness. It learns regularities, rules, abstractions and relations from the world using the sensory inputs it receives. Thus, it forms a model of the world where the animal is living. It also supports attention by deciding which aspects of the world are relevant at each moment.

The neocortex has a stereotypical six layered organization. Although many details vary, the overall structure is still recognisable throughout different cortical areas and species. This suggests that the neocortex can do all of its functions with variations of the same basic algorithm. This algorithm must be quite general and widely applicable because over the course of evolution, neocortex has expanded enormously and taken over many functions of other specialized, subcortical brain structures. For instance in human motor control, the motor cortex is a necessary executive organ without which we become paralysed. In contrast, in many other mammals such as rats, the whole neocortex can be removed without critically impairing motor behaviour.

So far our model of the neocortex supports learning and attention. The model consists of a large number of similar, interconnected information processing units, which interpret their inputs and make decisions about what information to broadcast based on the contextual inputs they receive from their neighbours. In such a network, global attention emerges from the units’ individual decisions to broadcast information (see “Complex networks and agent-based models” and “Cognitive Systems” for other related research).

The model is depicted in Figure 17. Each local neural population, or neural unit, learns and represents a set of different features from its inputs. Each unit receives bottom-up input vectors (solid blue arrows) and represents their regularities (features in machine learning terminology) by neural activation levels. In addition to the bottom-up inputs, the units receive information about other units through contextual inputs (dashed purple arrows). The units use the contextual information to improve their estimate about the identity of their bottom-up input and to make a decision about which features are the most relevant at the moment. The units make Bayesian inference about the identity of their bottom-up inputs implicitly, using contextual inputs as background information to refine their judgement.
The context-based associations are also used to assess the value of representing different features. So far we have experimented with evaluating the features based on their coherence with the context. The motivation is that it is better to represent those features which belong to the same object or event rather than represent features which belong to different objects or events. In practice this is achieved by highlighting context-supported features even more than Bayesian probability theory would suggest and then selecting only the most active features. In a network of processing units, this type of selection quickly singles out the features belonging to the most prominent object. The network automatically learns to perceive objects based on the associations between the context and the bottom-up inputs. This corresponds to finding Gestalt shapes.

Since it is usually beneficial to process and represent more than one object, we have added a mechanism to switch between different objects. Again, this process relies on a very simple habituation mechanism distributed among the processing units: the active output neurons gradually get “tired”. After a while some of the units start to make decisions to represent the features of another object and due to the context connections between units, this change escalates rapidly through the network and the network switches its attention to another object (Figure 18).

One of the most intriguing aspects of neocortex is its ability to come up with abstract, meaningful concepts. Our model uses so called competitive learning where the output neurons learn to respond even stronger to those inputs for which they became active. Since the contextual inputs modulate the activations strongly, they also have an important role in guiding learning. We have shown that in a hierarchical model like the one shown in Figure 17, the upper layers develop meaningful abstract representations. Moreover, since the emergent selection process in the network is able to attend to one object at a time, learning is faster because the features of different objects do not mix up.

So far we have not embedded the model into a larger cognitive architecture but this has been the goal in the design of the model. We are planning to include inputs from other “subcortical” modules as contextual inputs in order to bias attention and learning in the neocortical model. There are also various interesting possibilities to improve the model’s evaluation of important bottom-up inputs. For example, it is usually important to represent bottom-up inputs which are predictive of changes in context whereas the reverse temporal order indicates that the corresponding bottom-up inputs are not important. When receiving context from a motor system, such as the cerebellar model discussed in the previous section, and bottom-up inputs from sensors, such as cameras, the model could then learn to represent those visual features which are important for the motor behaviour of the system.

Figure 18 Jumping attention emerges in the cortex model. When the model was fed with the static image on the left, the network represented different images on different time instants: its attention focused on different objects in the image.
Integrating basal-ganglia and cerebellar models

Basal ganglia are an evolutionarily old system, and its homolog is found for example from all vertebrates. It is well conserved in evolution, suggesting a fundamental role in the brain function. Two main functions of basal ganglia are action selection and learning voluntary actions by trial and error.

Our research aims to combine the abovementioned model of cerebellar predictor, and a reinforcement learning model accounting of trial and error learning of new actions. Teaching a cerebellar predictor always needs an error signal, which from the biological viewpoint can be thought of as a reflex. In this scheme, learning new tasks would require a new handcrafted reflex signal every time. Moreover, designing workable reflex signal becomes increasingly tedious with the growing task complexity. This can be circumvented by using a reinforcement learner model of basal-ganglia to learn a coarse version of the required reflex from reward signal coming from environment. Moreover, addition of the cerebellar model can speed up the learning in a typically slow reinforcement based algorithm.

Actor-critic algorithms and cerebellar models have traditionally been studied separately. In a combined model, the role of cerebellum overlaps with the actor part of the reinforcement learning algorithm. Our goal is to learn, how the division of labour between the modules could be optimized.
Cognitive systems

In cognitive systems research, we have focused on studying the neural basis of active perception and emotions and we are strongly moving towards the study of brain in more naturalistic stimulus and task paradigms such as when viewing movies.

In our active perception research, we have continued our efforts to elucidate how the brain converts the stream of acoustic energy into features and objects, seamlessly combines auditory and visual information, memorizes the immediate past, predicts what is going to happen next, and prioritizes processing of relevant stimuli while maintaining capability to react quickly to unexpected events. As an everyday example, in a crowded cocktail party, one can selectively attend to a given conversation despite interference from multiple overlapping conversations, especially when seeing the lip movements of the speaker. Yet background noise and other conversations are automatically analyzed to some extent, as evidenced by attention being drawn to unexpected (i.e. unpredictable) events, such as one’s name being brought up in a background conversation. Further, the brain quickly adjusts to an unfamiliar accent of a new conversation partner, with such perceptual learning effects persisting over long periods of time, even up to a lifetime. In our theoretical framework (Jääskeläinen et al. 2007), we aim to unify aspects of task-relevant modulation (i.e., short-term plasticity) along the entire auditory pathway, from cortex to auditory periphery. Emotions, on the other hand, fundamentally shape our goals, and how stimuli are evaluated/processed in the brain (for a recent theoretical paper from our laboratory on this topic, see Alexandrov and Sams (2005).

Our research utilizes advanced, non-invasive human brain imaging methods, such as combined fMRI, MEG, and EEG, and linear causality modelling techniques. Our research scope is deliberately broad, ranging from bottom-up, largely stimulus-driven processes in auditory cortex to extra-acoustic influences on auditory processing, including selective attention and multisensory perception, with the use of both more traditional highly controlled and reduced stimulus/task settings as well as novel naturalistic stimulus/task paradigms and the associated new types of signal/data analysis approaches. We believe that this holistic approach is crucial for understanding the highly interactive and dynamic process of how internal and external contexts guide active hearing. We collaborate with our colleagues in Harvard Medical School, Boston, Georgetown University, Washington DC, and Northwestern University, Chicago, USA, to achieve our research goals.
Social systems

In social systems we focus on understanding how "microscopic" social interactions between a large number of individuals give rise to the "macroscopic" structure - the society. Consider, as an example, your everyday social life. You are likely to have repeated social interactions with a relatively small number of people (friends, colleagues, family members). It is also likely that many of these people are also bound to each other by social ties – your friends are very likely to be each other’s friends as well. In addition, these social ties surrounding you most probably form some kind of community structure, where you participate in several cliques, such as those consisting of your colleagues or friends sharing a same hobby.Zooming out of this local picture, these cliques and communities are in turn interconnected by social ties between their members as well as shared participants. Zooming out even further, we reach the societal level, where even larger-scale structures start to become visible - those formed by ties within and between socioeconomic classes, professional, political and scholarly communities, etc. You are part of a very, very large network of social ties.

Social networks have been the subject of intensive study since the 1930’s. In this framework, social life consists of the flow and exchange of norms, values, ideas and other social and cultural resources, and social action of individuals is affected by the structure of the underlying network. The structure of social networks is important then not only from the perspective of the individual, but also from that of the society as a whole. However, uncovering the structure of social networks has been constrained by the practical difficulty of mapping out a large number of individuals. Here, modern electronic databases offer unprecedented opportunities to uncover and explore large-scale social structures. Furthermore, by combining expertise in various fields such as social sciences, statistical physics, and computer science, we can simulate and study processes taking place on these enormous networks, such as diffusion of ideas and opinions. Our team was recently the first to show that very large social networks are, contrary to popular belief, not particularly optimal for unconstrained random flow of information. Rather, the structure tends to localize information within cliques. For any information to spread across the network, the "weak ties" connecting cliques have to be actively utilized. Currently, we are focussing on the dynamics of social networks inferred from communication records. Such dynamics takes place on several time scales, from the short-term time scale of communication events and patterns to the longer time scale of network rearrangement. Our first observations indicate clear traces of "causal" sequences of communication events where information is passed (e.g. from A to B to C). Furthermore, the observed short-term dynamics appears to slow down processes taking place on the level of the entire network, as compared to randomized reference dynamics with no short-term correlations.
Continuing our efforts to elucidate the neural basis of audiovisual integration, we tested for the feature specificity of adaptation of auditory-cortex magnetoencephalographic N1m responses to phonemes during lipreading. We presented eight healthy volunteers with a simplified sine-wave first-formant (F1) transition shared by /ba/, /ga/, and /da/, and a continuum of second-formant (F2) transitions contained in /ba/ (ascending), /da/ (level), and /ga/ (descending), during lipreading of /ba/ vs. /ga/ vs. a still-face baseline. N1m responses to the F1 transition were suppressed during lipreading, further, visual /ga/ (vs. /ba/) significantly suppressed left-hemisphere N1m responses to the F2 transition contained in /ga/. This suggests that visual speech activates and adapts auditory cortex neural populations tuned to formant transitions, the basic sound-sweep constituents of phonemes, potentially explaining enhanced speech perception during lipreading.

**Thematically related EEG study**

In a thematically related EEG study, we combined the McGurk effect with mismatch negativity (MMN), a response that is elicited in the auditory cortex at a latency of 100-250 msec by any above-threshold change in a sequence of repetitive sounds. An "odd-ball" sequence of acoustic stimuli consisting of frequent /va/ syllables (standards) and infrequent /ba/ syllables (deviants) was presented to 11 participants. Deviant stimuli in the unisensory acoustic stimulus sequence elicited a typical MMN, reflecting discrimination of acoustic features in the auditory cortex. When the acoustic stimuli were dubbed onto a video of a mouth constantly articulating /va/, the deviant acoustic /ba/ was heard as /va/ due to the McGurk effect and was indistinguishable from the standards. Importantly, such deviants did not elicit MMN, indicating that the auditory cortex failed to discriminate between the acoustic stimuli. Our findings show that visual stream can qualitatively change the auditory percept at the auditory cortex level, profoundly influencing the auditory cortex mechanisms underlying early sound discrimination.

**Project homepage: http://www.lce.hut.fi/research/css/systems/**

We also used whole-head magnetoencephalography (MEG) to record changes in neuromagnetic N100m responses generated in the left and right auditory cortex as a function of the match between visual and auditory speech signals. Stimuli were auditory-only (AO) and auditory-visual (AV) presentations of /pi/, /ti/ and /vi/. Three types of intensity matched auditory stimuli were used: intact speech (Normal), frequency band
filtered speech (Band) and speech-shaped white noise (Noise). The behavioural task was to
detect the /vi/ syllables which comprised 12% of stimuli. N100m responses were measured
to averaged /pi/ and /ti/ stimuli. Behavioural data showed that identification of the stimuli
was faster and more accurate for Normal than for Band stimuli, and for Band than for Noise
stimuli. Reaction times were faster for AV than AO stimuli. MEG data showed that in the
left hemisphere, N100m to both AO and AV stimuli was largest for the Normal, smaller for
Band and smallest for Noise stimuli. In the right hemisphere, Normal and Band AO stimuli
elicited N100m responses of quite similar amplitudes, but N100m amplitude to Noise was
about half of that. There was a reduction in N100m for the AV compared to the AO
conditions. The size of this reduction for each stimulus type was same in the left
hemisphere but graded in the right (being largest to the Normal, smaller to the Band and
smallest to the Noise stimuli). The N100m decrease for the Normal stimuli was
significantly larger in the right than in the left hemisphere. These results suggest that the
effect of processing visual speech seen in the right hemisphere likely reflects suppression of
the auditory response based on AV cues for place of articulation.

We used functional MRI (fMRI) to examine activation of the during strictly controlled
auditory attention tasks to show that selective auditory attention modulates neural activity
in the human inferior colliculus (IC) in addition to the human auditory cortex (AC). The IC
is an obligatory midbrain nucleus of the ascending auditory pathway with diverse internal
and external connections. The IC also receives a massive descending projection from the
AC, suggesting that cortical processes affect IC operations. In this study, 21 subjects
selectively attended to left-ear or right-ear sounds and ignored sounds delivered to the other
ear. IC activations depended on the direction of attention, indicating that auditory
processing in the human IC is not
only determined by acoustic input
but also by the current behavioral
goals. In another study, subjects
looked at emotion-evoking pictures
taken from the International
Affective Picture System database
while 32-channel EEG evoked
responses (ERPs) to an unchanging
auditory stimulus ("danny") were
collected. Effects of viewing
negative emotion pictures were seen
as early as 20 msec. Thus, it appears
that emotion can also affect
auditory function early in the
sensory processing stream.

**Collaborators**

Georgetown University, USA
Prof. Josef Rauschecker
Harvard Medical School, Boston, USA
Dr. Jyrki Ahveninen
Dr. Mark Anderman
Northwestern University, Chicago, USA
Prof. Niina Kraus
Russian Academy of Sciences, Russia
Prof. Yurii Alexandrov

Cognitive style in autism spectrum disorders

As a clinical research extension of our basic research efforts, we tested the detail-focused
cognitive style in autism spectrum disorders, which implies that persons with autism
spectrum disorders (ASDs) have a perceptual bias for local but not for global stimulus
features. The recognition of emotional facial expressions representing various different
levels of detail has not been studied previously in ASDs. We analyzed the recognition of
four basic emotional facial expressions (anger, disgust, fear and happiness) from low-
spatial frequencies (overall global shapes without local features) in adults with an ASD. A
group of 20 participants with Asperger syndrome (AS) was compared to a group of non-autistic age- and sex-matched controls. Emotion recognition was tested from static and dynamic facial expressions whose spatial frequency contents had been manipulated by low-pass filtering at two levels. The two groups recognized emotions similarly from non-filtered faces and from dynamic vs. static facial expressions. In contrast, the participants with AS were less accurate than controls in recognizing facial emotions from very low-spatial frequencies. The results suggest intact recognition of basic facial emotions and dynamic facial information, but impaired visual processing of global features in ASDs.

**Brain-computer interface studies**

Continuing on our brain-computer interface studies, we investigated whether inexperienced subjects could control a BCI accurately by means of visually-cued left versus right index finger movements, performed every 2 s, after only a 20-min training period. Ten subjects tried to move a circle from the center to a target location at the left or right side of the computer screen by moving their left or right index finger. The classifier was updated after each trial using the correct class labels, enabling up-to-date feedback to the subjects throughout the training. Therefore, a separate data collection session for optimizing the classification algorithm was not needed. When the performance of the BCI was tested, the classifier was not updated. Seven of the ten subjects were able to control the BCI well. They could choose the correct target in 84%-100% of the cases, 3.5-7.7 times a minute. Their mean single trial classification rate was 80% and bit rate 10 bits/min. These results encourage the development of BCIs for paralyzed persons based on detection of single-trial movement attempts.

In 2008, we also developed a BCI, which tetraplegic subjects could control only in 30 minutes. Six such subjects (level of injury C4-C5) operated a 6-channel EEG BCI. The task was to move a circle from the centre of the computer screen to its right or left side by attempting visually triggered right- or left-hand movements. During the training periods, the classifier was adapted to the user's EEG activity after each movement attempt in a supervised manner. Feedback of the performance was given immediately after starting the BCI use. Within the time limit, three subjects learned to control the BCI. We believe that fast initial learning is an important factor that increases motivation and willingness to use BCIs. We have previously tested a similar single-trial classification approach in healthy subjects. Our new results show that methods developed and tested with healthy subjects do not necessarily work as well as with motor-disabled patients. Therefore, it is important to use motor-disabled persons as subjects in BCI development.

**Neurocinematics study**

During 2008, we also took our first significant steps towards using more naturalistic stimulus paradigms in our neurocinematics study published in the Open Neuroimaging Journal by Jääskeläinen and colleagues. Specifically, hemodynamic activity in occipital, temporal, and parietal cortical areas were previously shown by others to correlate across subjects during viewing of a 30-minute movie clip, however, most of the frontal cortex lacked between-subject correlations. Here we presented 12 healthy naïve volunteers with the first 72 minutes of a movie ("Crash", 2005, Lions Gate Films) outside of the fMRI scanner to involve the subjects in the plot of the movie, followed by presentation of the last 36 minutes during fMRI scanning. We observed significant between-subjects correlation of
fMRI activity in especially right hemisphere frontal cortical areas, in addition to the correlation of activity in temporal, occipital, and parietal areas (see Figure 19). It is possible that this resulted from the subjects following the plot of the movie and being emotionally engaged in the movie during fMRI scanning. We further showed that probabilistic independent component analysis (ICA) can be used to reveal meaningful activations in individual subjects during natural viewing conditions.

Figure 19 We observed significant between-subjects correlation of fMRI activity in especially right hemisphere frontal cortical areas, in addition to the correlation of activity in temporal, occipital, and parietal areas. The inter-subject correlation maps are overlaid on A) sagittal, coronal and axial MRI slices and, B) on inflated cortical surfaces of left and right hemispheres.
6.3.2 Structure and Dynamics of Social Networks

Our focus areas are empirical analysis of data on large-scale social networks, the effects of observed structural features on processes taking place on such networks, as well as modelling the emergence of these features. This research has been closely related to the activities of the Complex networks and agent based models group (see Models & Methods), and also involves international collaborators from Budapest University of Technology (Hungary), University of Oxford (UK), University of Notre Dame (USA), and Harvard University (USA). In terms of complex network science, the main focus of the empirical research line is on linking social tie strength and communication patterns of individuals to the overall network structure.

Uncovering structural properties of large social networks has been so far constrained by the practical difficulty of mapping out interactions among a large number of individuals. Hence, most social science studies deal with analyzing questionnaire data, typically only reaching the order of N=100 individuals. The benefit of this approach is that the spectrum of social interactions accessible to studies is wide. However, as a downside, the strength of an interaction is harder to quantify; in questionnaire-based data, it is based on recollection and, consequently, is highly subjective. However, the availability of electronic databases from emails to phone records has recently attracted the interest of both sociologists and (statistical) physicists. These databases provide unprecedented opportunities for modern social network analysis – social networks as large as millions of individuals may be handled, and although the range of social interactions is evidently narrower (e.g. email or phone communication), all information is objectively quantifiable. Although both approaches have their merits, studying large scale networks may better shed light on how individual microscopic interactions translate into macroscopic social systems. In addition to this being one of the key questions as posed by social scientists, it is also the one to which statistical physics in general, and the science of complex networks in particular, can make a contribution.

In 2008, we have continued studies of social networks inferred from mobile phone call records, where the first results were published in 2007 (see Onnela et al., Proc. Natl. Acad. Sci. (USA) 104, 7332 (2007); Onnela et al., New J. Phys. 9, 179 (2007)). The (anonymized) call records have been extracted from the customer data base of a mobile network operator, whose customer base is approximately 20th of the population of its country of operation. In the network analysis, the subscriptions (i.e. mobile phone users) are represented as the network’s nodes. They are interconnected by a link if the two users have both called each other during the investigated period, and we use the aggregated call minutes between people as a proxy of the social tie strength. Our first results concerned the relationship of tie

Project homepage: http://www.lce.hut.fi/research/css/networks/
strengths to network topology, verifying the Granovetter hypothesis. In 2008, we have extended our studies to include communication patterns – each call or text message in the database is time-stamped, so we have full knowledge of how frequently and when people communicate. Our first results indicate clear causal behaviour – incoming calls trigger outgoing calls within a relatively short time (see Lauri Kovanen, Structure and dynamics of a large-scale complex social network, Master’s Thesis, 2009) and there are clear traces of even longer chains of communication events. We have also identified inherent biases in calling behaviour – many social relationships appear such that one party tends to initiate communication. Our next target is to move on from communication patterns between individuals to communication patterns within social groups, and attempt to link observed patterns with the nature of the groups.

In addition to empirical analysis, we have studied a number of social network models, proposed in the complex networks literature, and analyzed their features and connections to traditional network models in the social sciences (Toivonen et al, A comparative study of stochastic algorithmic models for social networks, submitted (2008)). Special attention has been paid to features such as emergent formation of social groups. Related to the latter, we have also continued our studies of the dynamics of opinion formation processes on networks containing community structure, published in Toivonen et al, Phys. Rev. E 79, 016109 (2009). Here the focus has been the nature of “trapping” effects associated with dense social groups which are only sparsely interconnected (see Figure 20).

Figure 20  The mobile communication network employed in social network studies contains communities, i.e. groups of people with frequent and dense social ties. The above figure displays a large community detected in this network. The arrows indicate phone calls taking place within this group, at around 2 AM on New Year's night, 2007.
6.4 Computational Health

Computational health focuses to understand biological systems at various levels (molecular, cellular, tissue, organ and individual) through computational modelling and information theoretic data and image analysis methods. With the most up-to-date computational approaches and modern experimental biotechnology, it has become possible to understand the structure and functions of biomolecules, information stored in DNA, its expression to proteins, protein structures, metabolic pathways and networks, intra- and intercellular signalling, and the physico-chemical mechanisms involved. COSY has been concentrating mainly to various computational approaches and method development of systems biology in close collaboration with researcher of medicine and biology.
6.4.1 Bayesian Modelling and Applications

**Analysis of healthcare data**

Focus of the project is to develop methods for healthcare data analysis. The goal is to create tools to aid healthcare agents (e.g. doctors and administration) to produce and evaluate regional healthcare key figures, and anticipate the expected cost effect of a treatment for a single patient or a treatment process. The emphasis is on development of methods for analysis of large scale healthcare data, for example, available in patient registries and mortality records. The project is a part of Tekes FinnWell - Healthcare technology programme.

Bayesian hierarchical methods make it possible to combine group-level and individual-level information in a flexible way, and nonlinearities and possible interactions between covariates can be automatically learned from the data, for example, with Gaussian process models. Implicit interactions allow also characterizing some of the hierarchical structures that are often modelled explicitly. Due to high-dimensional data and difficulties in interpreting and explaining the results of the complex models, one of the objectives is to obtain clear and understandable visualisations for the results. Pilot projects for the analysis of large scale patient data are analysis of institutionalisation of the elderly in city of Vantaa and the treatment of hip fracture patients in various hospital districts in Finland.

In Vantaa pilot the goal was to predict institutionalization and find groups with relatively high risk. The data set included different care events (nursing home periods, physician visits, home care etc) from registers of Vantaa city and Stakes. The data were modeled using Gaussian processes, after which an informative subset of covariates was chosen with variable selection. Using a smaller set of covariates made it easier to visualize the data and study combinations of factors which affected risk. As expected, institutionalization was predicted more accurately by register data than mere age and gender which are traditionally used. Groups with different risk levels were found. In groups with no care events or no events except home care, the risk is low and increases with age and with number of daily home care visits. Higher risk groups are described by different risk factors, e.g. functional capacity, number of hospital days and having nursing home periods, and age and home care has less effect.

---

**Senior researchers**
Aki Vehtari  
Jouko Lampinen  
Simo Särkkä

**Researchers**
Jouni Hartikainen  
Juho Kettunen  
Elina Parviainen  
Jaakko Riihimäki  
Miika Toivanen  
Jarno Vanhatalo

---

Project homepage: [http://www.lce.hut.fi/research/mm/model/](http://www.lce.hut.fi/research/mm/model/)
In the hip fracture pilot, the objective is to research the prediction accuracy for the lengths of stay in sequential states of the treatment chain after a fractured hip. The project is conducted in co-operation with National Research and Development Centre for Welfare and Health (Stakes). In modelling the length of stay, parametric models such as the Coxian phase-type distributions and Weibull mixture models were considered first. The results showed that these parametric models did not capture well the characteristics in the data, and therefore a nonparametric Bayesian multilayer perceptron (MLP) model was used as a flexible alternative to predict the patient length of stay. Since there were nonlinearities and interactions in the model, average predictive comparisons were studied to assess the relevances of covariates in the prediction. The current development focuses on using Gaussian processes instead of the MLP model, and implementing a variable selection method for the Gaussian processes to increase the interpretability of the models.
Spatial and spatio-temporal epidemiology

Spatial epidemiology seeks to reveal geographical variations in health outcomes and risks to health. The objective has been to create computationally efficient tools that provide accurate and easily interpretable results for the use of healthcare authorities.

In the first phase of the project, we created a customized GIS (Geographical Information Systems) tools to estimate and visualize geographical variations in relative risk of death. The adaptive binned kernel estimation method involved the use of circular computation areas operated on a grid with a maximum resolution of 250 m x 250 m allowed by the data. Risk estimates were based on comparing area-specific expected numbers of deaths to actual death counts within an averaging moving window.

The exploratory method featured fast and interactive creation of disease maps due to a simple algorithm and graphical interface. Its primary purpose will be to provide preliminary analysis over large scopes of data, but it does not facilitate the inclusion of explanatory variables aiding further understanding of the detected phenomena. For this reason the focus of the research has moved towards Bayesian spatial methods that provide an improved control on smoothing and statistical significances, and the flexible use of explanatory variables.

The Bayesian models studied utilize Gaussian processes, whose advantage is the flexibility in choosing the spatial covariance structure. The challenges with using Gaussian processes in spatial modeling are the inference time and memory requirements that scale unfavorably as a function of number of data points, and that the models are analytically
intractable. These difficulties lead to a need of approximate computational methods that have been the main focus of the research for few years.

The methods under study include sparse Gaussian processes and analytical approximations for high dimensional integrals. The sparse Gaussian processes utilize special kind of covariance functions that lead to computationally faster implementation compared to traditionally used covariance functions. The approximate integration has been implemented using Laplace approximation and expectation propagation algorithm. The approximations are very fast to evaluate, and give very accurate results in the spatial models.

We have also extended the Gaussian process based disease mapping models from spatial to spatio-temporal domain. This enables the investigation of temporal dynamics of the spatial distribution of disease risk, and thereby extends the potential scope of disease mapping analysis. The covariance structure of the model is formulated such that the risk is assumed of being composed of independent spatial and temporal components as well as a component, in which space and time are coupled. Currently using the developed methods allow inference for data sets exceeding 20000 data points. The constructed models were tested with three municipal level cancer data sets with interesting results. While the temporal component was strongly present in each data set, clear spatial and spatio-temporal patterns were also identified.

The constructed spatio-temporal models were also applied to life expectancy estimation by replacing the time component with age group component, and then using the smoothed death rate estimates in traditional life table calculations. This approach has the advantage that it induces correlations among space and age dimensions, whereas traditional life table analysis usually assumes them to be independent, and provides realistic uncertainty estimates for the life expectancies.

Figure 23 Estimated relative risk of death caused by cerebral vascular diseases between 1995 and 2000. A zoomed-in image from Turku region. The resolution is 250 m x 250 m.
Bayesian Estimation of Dynamic Systems

The goal of the project is to develop new methods for modeling and estimation of time-varying stochastic processes and random fields. The problem itself is quite mature and the related efficient recursive estimation methodology is called optimal filtering. Optimal filtering refers to the methodology that can be used for estimating the states of time varying systems, which are indirectly observed through noisy measurements. In this project we have concentrated to estimation methods for non-linear and non-Gaussian systems, because the linear Gaussian case can be completely solved using the celebrated Kalman filter. In addition to non-linear systems, one of the current focus areas is estimation in spatio-temporal systems, which can be considered as infinite-dimensional generalizations of classical optimal filtering models.

In methodological sense we have developed new estimation methods for both discrete-time and continuous-time stochastic dynamic systems and the developed methods have been documented publications in [1] and [2], respectively. We have also continued the research on application of new Bayesian methodology such as variational Bayesian learning to dynamic estimation and one of the methods has been published in [3]. Similar estimation problems also arise in spatial epidemiology, in analysis of spatio-temporal health care data. During the project we have also developed new expectation propagation (EP) and assumed density filtering (ADF) based Bayesian methodology for estimation in infinite-dimensional spatio-temporal models arising in the application [4].

As an interdisciplinary research project we have been collaborating with the Department of Engineering Design and Production (former Laboratory of Automotive Engineering) at Aalto University for developing statistical estimation methods used in estimating the maximum friction potential between tyre and road. The knowledge of the friction potential is imperative for the various vehicle safety systems to work effectively. We have developed Bayesian methods [5] for dynamically classifying near infrared spectroscopy measurements obtained from road surfaces. These classification results are used in conjunction with vehicle dynamics estimators for estimating the friction potential for different road types.

Temporal and spatial estimation problems also arise in brain signal measurement systems and brain imaging, and one of the target applications of the methodology is the new Inverse Imaging (InI) based fMRI measurement system. In that application the purpose is to estimate the temporal and spatial locations of activations in brain by measuring its magnetic response. During the year 2009 we have started developing new statistical methodology for this application.

The Oxford affiliate unit of Complex Systems and Network Research (CSNR) functions as a framework for collaborations between COSY and researchers at Oxford University, especially those in the cross-departmental CABDyN research cluster. CABDyN is a multi-disciplinary team involving Physics Department, Said Business School, Department of Engineering Sciences, and Mathematics Institute. COSY and CABDyN share a common interest in studying complex networks and agent based models, including modelling network formation and collective dynamics and developing novel structural characteristics for weighted complex networks.

CSNR is locally run by Dr. Jukka-Pekka Onnela, a Junior Research Fellow of Wolfson College, Oxford University (spending the last third of 2008 at Harvard University as Fulbright Fellow) and staffed by M.Sc. Phillip Staniczenko as graduate student in physics. In addition, professor Kimmo Kaski as Supernumerary Fellow of Wolfson Collage is in CSNR as part time head. One of the aims is to work on projects that combine the competence developed at COSY in dealing with weighted complex networks with the application domain specific knowledge of different researchers in Oxford.

One such example is a project related to developing a mathematical framework that allows coupling network structure and function. More specifically, the topology of the network evolves according to some specified microscopic rules and there is a dynamic process taking place on the network that both depends on its structure but is also capable of modifying it. As such it is a generic framework for dealing with the types on systems in which network structure, dynamics, and function are interrelated. The fruits of this type joint research with Oxford scientists is the analysis and modelling studies of social networks, more specifically mobile communication based social network.
7 Research Activities

7.1 Visits to the Laboratory

- Dr. Jyrki Ahveninen, Harvard Medical School, Massachusetts, USA
- Prof. Rafael Barrio, Universidad Nacional Autónoma de Mexico UNAM, Mexico
- Dr. Harry Bronson, University of Western Sydney, Australia.
- Dr. Marshall Dawson, Northwestern University, USA
- Dr. Eyton Domain, Panchman Institute, Israel
- Prof. Sir Roger Elliott, Oxford University, U.K.
- Prof. R. Holland Cheng, the Department of Molecular and Cellular Biology, University of California, Davis, CA, USA
- Dr. Lin Fa-Hsuan, Institute of Biomedical Engineering, National Taiwan University, Taiwan
- Dr. Santo Fortunato, Complex Networks Lagrange Lab, Institute for Scientific Interchange (ISI), Torino Italy
- Prof. Alex Hansen, Department of Physics, Norwegian University of Science and Technology, Trondheim, Norway
- Prof. Janos Kertesz, Budapest University of Technology, Hungary
- Dr. Nina Kraus, Northwestern University, USA
- Prof. David Landau, The University of Georgia, USA
- Dr. Peter Liljeroos, University of Stockholm, Sweden
- Prof. Andrej Nowak, Department of Psychology, University of Warsaw, Poland
- Raij Tommi, Harvard Medical School, USA
- Dr. Peter Richmond, Trinity College, Ireland
- Prof. Jorma Rissanen, IBM, California, USA
- M.Sc. Yukie Sano, Tokyo Institute of Technology, Japan
- Dr. Marc Sato, University of Grenoble, France
- Dr. Jean-Luc Schwartz, University of Grenoble, France
- Dr. Takashi Shimada, University of Tokyo, Japan
- Dr. David Sherrington, Oxford University, UK
- Dr. Erkki Somersalo, Case Western Reserve University, USA
- Dr. Kelly Spencer, Colgate University, USA
- M.Sc. Gergely Tibely, Budapest University of Technology, Hungary

7.2 Visits by the Laboratory Personnel

Kimmo Kaski

- The National Autonomous University of Mexico
- Oxford University, UK
- University of Tokyo and Tokyo University of Technology, Japan
- Noertheastern University of Boston, USA
- University of Warsaw, Poland
Mikko Sams
- Institute of Psychology of Russian Academy of Sciences, Russia

Iiro Jääskeläinen
- University of Grenoble, France
- Massachusetts General Hospital - Harvard Medical School - Massachusetts Institute of Technology Athinoula A. Martinos Center for Biomedical Imaging, Charlestown, Massachusetts, USA
- Georgetown University, USA

Marton Karsai
- Budapest University of Technology and Economics, Hungary
- Northeastern University, USA
- University of Warsaw, Poland

Mikko Kivelä
- ISI Foundation, Italy
- EDEN meeting, Faro, 11.-14.2.2009, Portugal
- EDEN meeting, Mallorca, 17.-18.9.2009, Spain

Lauri Kovanen
- University of Warsaw, Poland

Jari Saramäki
- Oxford University, UK
- ISI Foundation, Italy
- EDEN meeting, Faro, 11.-14.2.2009, Portugal

Jenni Hulkkonen
- The Center of Marine Sciences, Portugal

Pentti Jääskeläinen
- European Molecular Biology Laboratory, Germany

7.3 Participation in Conferences and Seminars

Kimmo Kaski
- Order, Robustness and instabilities in Complex systems, Geilo, 29.3-2.4., Norway. Social Networks: Can we analyse and model them?
- COST MP801 WG4 Meeting, Durham, 15.-18.4.2009. Invited paper: Social Networks: can we model them?
• International conference on Discrete models of Complex Systems, Gdansk, 22.6.-
24.6.2009, Poland. Invited paper: Complex Social Networks: Can they modeled?
• COST MP801 Conference and Council Meeting, Rome, 27.5-31.5.2009, Italy
• University of Kioto, Yykowa Institute of theoretical physics, summer school workshop, 
computationally modelled?
• ECCS 2009 "Dynamics On and Of Complex Networks III", Warwick, 22.-24.9.2009, 
UK. Invited paper: Social networks: can they be modelled?

Jouko Lampinen
• IJCCI 2009, 5.-7.10.2009, Madeira, Portugal. Invited paper: Probabilistic View on 
Self-organizing Maps and Dimension Reduction.

Mikko Sams
• RIKEN BSI Joint Workshop on Cognitive and Social Brain, Tokyo, 25.-26.5.2009, 
Japan. Invited paper: Active hearing.
• 2nd International Conference on Imaging in Neuroscience, Tromso, 9.-13.9.2009, 
Norway. Invited paper: Magnetoencephalographic applications.
• Learning Mind and Brain, Moscow, 16.-20.11.2009, Russia

Jukka Tulkki
• MRS Fall Meeting, 30.11.-4.12.2009, Boston, USA

Jouni Hartikainen
Analysis of Disease Incidence with Sparse Gaussian Processes

Oskari Heikkilä
emitting diodes for high efficiency operation

Teppo Häyrynen
for Beam Splitters and Optoelectronic Devices. Over 100 participants, of which over 
one half international.

Iiro Jääskeläinen
• Fifth Conference on Mismatch Negativity and its Clinical and scientific applications, 
Budapest, 4.-7.4.09 Hungary. Invited paper: Differential adaptation of auditory cortex 
neural populations as the neurophysiological basis of MMN.
• Gibsa Laboratory, Grenoble, 9.-12.7.09, France. Invited paper: Audiovisual speech 
perception and the speech motor system: fMRI and MEG studies.
• Society for Neuroscience, Chigaco, 17.-21.10.2009, USA. Inter-subject correlations in 
low-frequency prefrontal fMRI-BOLD activity during watching a movie.
• Georgetown University, Washington DC, 27.10.2009, USA. Invited paper: Effects of 
speech reading on auditory processing in the human brain.

Jaakko Kauramäki
• Neuroscience 2009, Chicago, 17.-21.10.2009
Lauri Kovanen
- COST Action MP0801 Workshop, Italy. Poster: Causality and Reciprocity in a Complex Social Network

Jani Oksanen

Elina Parviainen

Jari Saramäki

Toivanen Miika
- International Workshop on Computer Vision and Its Application to Image Media Processing, Tokyo, 10.-15.1.2009, Japan. Matching Corresponding Points from Unannotated Images with Bayesian Methods.

Harri Valpola

Jarno Vanhatalo

Aki Vehtari

Mikko Viinikainen
- BrainTuning workshop, 5.-6.2.2009, Helsinki, Finland. Poster: Perceived valence of sounds is represented non-linearly in the human amygdala and auditory cortex.

### 7.4 Memberships in Scientific Societies

**Kimmo Kaski**
- Fellow by invitation of the American Physical Society, USA
- Member of Association for Computing Machinery
- Fellow by invitation of the Finnish Academies of Technology
- Fellow and Chartered Physicist by invitation of the Institute of Physics, UK
- Member by invitation, Academica Europaea
- Member of American Association for the Advancement of Science (AAAS), USA
- Fellow by invitation of the Finnish Academy of Science and Letters
- Supernumerary Fellow, Wolfson College, University of Oxford, UK
- COST (European Cooperation in Science and Technology) Committee member

**Jouko Lampinen**
- Board member of Brain Research Society of Finland (BRSF)
- Member of International Neural Network Society (INNS)
- Member of Pattern Recognition Society of Finland, Hatutus (member of IAPR)

**Harri Valpola**
- Board member of Finnish Artificial Intelligence Society
- Member of Pattern Recognition Society of Finland, Hatutus (member of IAPR)

**Aki Vehtari**
- Board member of Pattern Recognition Society of Finland, member-society of IAPR (International Association for Pattern Recognition)
- Fellow of the Royal Statistical Society
- Member of the International Society for Bayesian Analysis
- Member of the European Network for Business and Industrial Statistics
7.5 Other Activities

Kimmo Kaski

- Pre-examiner of a doctoral thesis Institute of Mathematical Sciences, Pan Raj Kumar, India.
- Member of Committee on the development of computational Science in Finland, Ministry of Education
- The Editorial Board in International Journal of Modern Physics C
- Reviewer for European Science Foundation - Review of Self-organized nanosystems
- (SONS) programme Science Foundation Ireland - Programme Review
- Belgian Science Policy Office: Interuniversity Attraction Poles network review
- Reviewer in Journals
  - Physical Review Letters
  - Physical Review E
  - Physica A
  - International Journal of Modern Physics C

Mikko Sams

- Board member (representing Helsinki University of Technology) of the BioMag laboratory
- Vice chairperson of the board of CICERO learning network
- Expert member in the Board of the Advanced Magnetic Imaging Center, Helsinki University of Technology
- Member of the Editorial Board in journals:
  - Tiede
  - Polysteekki

Jukka Tulkki

- Pre-examiner of a doctoral thesis
  - Anna Sankari, Oulu University
  - Jaime Zaratiegu, Oulu University
  - Hannu-Pekka Komsa, Tampere University of Technology
- Opponent of a doctoral thesis
  - Anna Sankari, Oulu University

Iiro Jääskeläinen

- Reviewer in journals, book series and international conferences:
  - Journal of Neurophysiology
  - Brain and Cognition

Jari Saramäki

- Member of Scientific Advisory Board, Xtract Ltd.
- Reviewer in journals, book series and international conferences:
  - Physical Review Letters
  - Physical Review E
  - Physica A
  - European Physical Journal B

Harri Valpola
• Member of Editorial Board:
  *Neurocomputing*

• Board member
  *Finnish Artificial Intelligence Society*

• Reviewer in journals, book series and international conferences:
  *New Journal of Physics*

Jarno Vanhatalo

• Fellow of
  *The Royal Statistical Society*

Aki Vehtari

• Reviewer in journals, book series and international conferences:
  *Scandinavian Journal of Statistics*
  *IEEE Transactions on Neural Networks*
  *International Journal of Engineering Simulation*
  *International Journal of Computer Systems Science & Engineering*

Antti Yli-Krekola

• Reviewer in journals:
  *Neurocomputing*
## 8 Publications

### 8.1 Publications in Refereed Journals

<table>
<thead>
<tr>
<th>Authors</th>
<th>Title</th>
<th>Journal</th>
<th>Volume</th>
<th>Issue</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andersen, T. S.; Tiippana, Kaisa; Laarni, J.; Kojo, I.; Sams, Mikko</td>
<td>The role of visual spatial attention in audiovisual speech perception</td>
<td>Speech Communication</td>
<td>51</td>
<td>2</td>
<td>184-193</td>
</tr>
<tr>
<td>Auranen, Toni; Nummenmaa, Aapo; Vanni, S.; Vehtari, Aki; Hämäläinen, MS.; Lampinen, Jouko; Jääskeläinen, Iiro</td>
<td>Automatic fMRI-guided MEG multidipole localization for visual responses</td>
<td>Human Brain Mapping</td>
<td>30</td>
<td>4</td>
<td>1087-1099</td>
</tr>
<tr>
<td>Eisler, Zoltan; Kertesz, Janos; Lillo, Fabrizio; Mantegna, Rosario N</td>
<td>Diffusive behavior and the modeling of characteristic times in limit order executions</td>
<td>Quantitative Finance</td>
<td>9</td>
<td>5</td>
<td>547-563</td>
</tr>
<tr>
<td>Heikkilä, Oskari; Oksanen, Jani; Tulkki, Jukka</td>
<td>Ultimate limit and temperature dependency of light-emitting diode efficiency</td>
<td>Journal of Applied Physics</td>
<td>105</td>
<td>9</td>
<td>093119</td>
</tr>
<tr>
<td>Heimo, Tapio; Kaski, Kimmo; Saramäki, Jari</td>
<td>Maximal spanning trees, asset graphs and random matrix denoising in the analysis of dynamics of financial networks</td>
<td>PHYSICA A</td>
<td>388</td>
<td>2-3</td>
<td>145-146</td>
</tr>
<tr>
<td>Häyrynen, Teppo; Oksanen, Jani; Tulkki, Jukka</td>
<td>Exact theory for photon subtraction for fields from quantum to classical limit</td>
<td>Europhysics Letters</td>
<td>87</td>
<td>4</td>
<td>44002</td>
</tr>
<tr>
<td>Häyrynen, Teppo; Oksanen, Jani; Tulkki, Jukka</td>
<td>On the origin of divergences in the coincidence probabilities in cavity photodetection experiments</td>
<td>Journal of Physics B: Atomic, Molecular and Optical Physics</td>
<td>42</td>
<td>14</td>
<td>145506</td>
</tr>
<tr>
<td>Iñiguez, Gerardo; Kertész, János; Kaski, Kimmo; Barrio, Rafael</td>
<td>Opinion and community formation in coevolving networks</td>
<td>Physical Review E</td>
<td>80</td>
<td>6</td>
<td>066119</td>
</tr>
<tr>
<td>Kumpula, Jussi; Onnela, J.P.; Saramäki, Jari; Kertesz, Janos; Kaski, Kimmo</td>
<td>Model of Community Emergence in Weighted Social Networks</td>
<td>Computer Physics Communications</td>
<td>180</td>
<td>4</td>
<td>517-522</td>
</tr>
<tr>
<td>Lambiotte R.; Saramäki Jari; Blondel VD.</td>
<td>Dynamics of latent voters</td>
<td>Physical Review E</td>
<td>79</td>
<td>4</td>
<td>046107</td>
</tr>
<tr>
<td>Lehtola, Ville; Linna, Riku; Kaski, Kimmo</td>
<td>Dynamics of forced biopolymer translocation</td>
<td>Europhysics Letters</td>
<td>85</td>
<td>058006</td>
<td>1-6</td>
</tr>
<tr>
<td>Mäkinen VP; Forsblom C; Thorn LM; Waden J; Kaski Kimmo, Ala-Korpela, M; Groop, P. - H.</td>
<td>Network approach to type 1 diabetes: association patterns between diabetic...</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mäkinen, VP; Forsblom, Carol; Thorn, Lena; Waden, Johan; Kaski, Kimmo; Ala-Korpela, Mika; Groop, Per-Henrik : Network of vascular diseases, death and biochemical characteristics in a set of 4,197 patients with type 1 diabetes (The FinnDiane Study). Cardiovascular Diabetology, 2009. Vol. 8, No. 54.


8.2 Conference Proceedings and Abstracts


