



Aalto University Research Assessment Exercise 2009

Panel Reports

Panel 3: Mathematics and Physics

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Panel Chair:

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Panel Members:

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Prof. Joachim Rosenthal, University of Zürich, Switzerland

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Units of Assessment:

Department of Biomedical Engineering and Computational Science, Helsinki University of Technology (TKK)

Department of Mathematics and Systems Analysis, Helsinki University of Technology (TKK)

Department of Applied Physics, Helsinki University of Technology (TKK)

Department of Micro and Nanosciences, Helsinki University of Technology (TKK)

Low Temperature Laboratory, Helsinki University of Technology (TKK)

Overview

This panel reviewed five Units of Assessment at TKK which ranged from basic to applied physics, to elements of electrical and computational engineering, and applied mathematics. In addition to the assessment and evaluation of each separate unit, we wish to provide the following summary.

1) In terms of research, each of the units had robust research activity which should be generally characterized as quite strong on average. In a number of individual instances, this research clearly competes at world-class level, if not outright leading a subfield.

2) The present structure of the four departments combining physics, applied physics, and electrical/computational engineering (i.e. excluding mathematics) seems to have enjoyed some benefits of past history as well as more recent reorganization. However, to an outsider, the manner by which these units have been organized appears in several cases somewhat contrived and artificial in terms of clear disciplinary rationale. Accordingly, the

panel witnessed a certain amount of fractionalization, duplication, and awkward positioning/competing for resources. In the context of the new Aalto University, the panel strongly recommends that the present structures be thoroughly revisited in order to provide a more competitive sum of what are generally quite useful and high quality scientific parts.

3) The makeup of the faculty as well as senior research staff reflects a significant amount of “inbreeding” to a degree rarely seen in any top research university. There are many reasons for this, but the net effect is a somewhat inward-looking and insular character to the units, in spite of some strong individual faculty efforts to “internationalize”. Hiring faculty with no significant international experience (either with a doctoral degree acquired abroad or by an extensive postdoctoral period abroad) is detrimental to scientific excellence. The shift of faculty hiring to a tenure track-type system is surely a necessary condition (though not sufficient in its own right). What is particularly unattractive in the present system is the way junior scientific staff remains in a “career holding pattern” while waiting for a professorship to open.

4) The management of Aalto University should adopt a strategy of internationalization, which might consist of following components:

- Organizing yearly international summer schools of Aalto University at the doctoral level, with lectures and participation in research, attracting the best possible students for doctoral studies at Aalto.
- Strongly encouraging Finns who aspire to academic positions at Aalto University to have international experience either as doctoral students or postdoctoral researchers.
- Strongly encouraging professors and senior researchers to achieve such experience by introducing accelerated sabbaticals (say, one year each five years) spent at foreign universities or research institutions.
- Supporting formation of international networks of excellence initiated by professors and researchers at Aalto University, going beyond national or even European networks of excellence.

Without such clear-cut and well funded strategy of internationalization of Aalto University we doubt that a truly international visibility of Aalto could be achieved.

5) All the five units which the panel reviewed are very important and should be present in any first class research university. One issue which the panel wishes to single out is the Mathematics Department, which is presently effectively an Applied Mathematics department (and a good one at that). It is not possible to operate a high profile university without a strong mathematics department including both pure and applied mathematics components – both for the sake of the discipline itself and its pivotal role in educating scientists and engineers.

6) There is no formal research program at Aalto University in Life Sciences. We believe that many of the activities we reviewed would benefit strongly by the establishment of strong programs in Biotechnology, Molecular Biology, and Genetics. The decision on such an initiative has to be taken at the University management level, via a process of careful consultation with the members of the relevant scientific units.

7) We certainly appreciated the hospitality of the units in hosting the panel. In most cases the organization of the presentations was thoughtful even if the hectic timetable made it difficult to reach deeper into the units' research topics. Further, not all department leadership was always present. For example, while timing is never perfect, apparent conflicts prevented the full leadership of the high quality COMP unit in Applied Physics being present.



Department of Biomedical Engineering and Computational Science, TKK

1. Introduction and General Impressions

The Department of Biomedical Engineering and Computational Science (BECS) consists basically of two parts: the Laboratory of Biomedical Engineering (BME) and the Laboratory of Computational Engineering (LCE). The unique combination of the two disciplines and the resulting esprit de corps embodies the integrative spirit of Aalto University (as we understand it).

The main areas of research are:

1) Computational Science including modeling large networks e.g. social networks, mobile phone networks, ecological networks, epidemiology and finally also neural networks. The general unifying theme which puts this research at the cutting edge of innovative physics is the creation of new methods and the use of powerful computational tools for the study of complex systems with very large number of degrees of freedom.

2) Bioelectromagnetism instrumentation and brain function including Magneto- and Electroencephalography MEG/EEG, Magneto- and Electrocardiography MCG/ECG, navigated Transcranial Magnetic Stimulation TMS, Near Infrared Imaging NIRS, hybrid MEG-MRI, biosignal analysis and inverse problem of MEG/EEG, brain excitability and connectivity.

In addition we find projects on biopolymer dynamics, and DNA elasticity, retinal mechanisms of vision and retina as a biosensor, thermophotonic heatpump, clustering methods and quantum dots.

The roots of BME go back to Prof. Toivo Katila. Here, too, researchers at TKK can look back to a most significant success story: the development of a multichannel SQUID systems leading to completely new methods in brain imaging research including the genesis of a spin-off company Neuromag (now with Elekta and with worldwide reputation). An additional contribution by the BME leaders and their collaborators has been the development of a transcranial magnetic stimulation system (TMS) - another unique achievement that led to the spin-off Nexstim. The BME team is presently probing entirely new frontiers by the proposed project on a hybrid MEG-MRI system that is now granted by the EU.

LCE has achieved major impact mainly via its activities in the framework of two Centers of Excellence of the Academy of Finland in the areas of Computational Materials Research, Information Technology and Cognitive Science, and subsequently by its research on Complex Systems, in particular studies of various physical and social networks.

Today's structure of BECS has two main roads (1 and 2, see above) and some sidetracks. There is a clear link between brain instrumentation/brain research (within BME) and complex networks (within LCE) via neural networks and modeling of complex systems. The links to other research areas are not clearly visible.

The two main areas of research are excellent and clearly on a very high international level: the number of publications in peer reviewed journals and the number of citations is extremely large.

BME and BioMag were partners in the Center of Excellence (CoE) of the Academy of Finland (Helsinki Brain Research Center 2002-2007) whereas the LCE received Center of Excellence status first in 2000-2005 and currently leads the CoE COSY: Computational Analysis, Modeling, and Simulation of Complex Systems (2006-2011).

The interdepartmental study program on Bioinformation Technology (BioIT) attracts very many engineering students of the highest academic quality. The panel acknowledges that several young researchers have spent significant time at leading universities abroad. These researchers brought in new expertise and directions of research and created excellent international connections.

2. The Unit's Research and the Research Strategy of the Unit's Home University

BECS clearly reflects the research strategy of TKK and Aalto University: The LCE program fits perfectly into "information and communication" and BME fits perfectly into "health and well being". BME contributes significantly to Brain imaging, Brain research and the Advanced Magnetic Imaging Centre AMI - a worldwide known expertise of TKK.

BECS is an active participant in the aivoAalto project bringing together engineering, business and arts in the Aalto University.

There is a long tradition of thematic connections between the successes of BME and the Low Temperature Laboratory that has sprung from the pioneering early work at LTL on SQUID-based brain sensors. For example, Risto Ilmoniemi, while working in LTL was one of the authors of "Magnetoencephalography – theory, instrumentation and applications", published in *Reviews of Modern Physics* 65, 413-497, 1993, with 1338 citations. Our thoughts about the desired relationship of this unit with parts of the Low Temperature Lab are presented in Sec. 8.

We see an opportunity in possible collaboration between the economic modeling activities at the LCE and researchers from the Helsinki School of Economics.

3. Scientific Quality of the Unit's Research

Numerical Rating (1-5): **5 Outstanding International Level**

The scientific quality in the two main areas of research is excellent. The early research on multichannel MEG systems at the Low Temperature Laboratory, pioneered by Prof. Ilmoniemi and colleagues, was outstanding. As an institution, TKK developed a worldwide leadership in advancing instrumentation development for magnetic detection of neural signals, including multichannel capability with superb noise management. As another important contribution by researchers at TKK (both BME, the Low Temperature Lab, and collaborators), important new tools were developed by image reconstruction algorithms to solve the complex problem of MEG and EEG. As a prime example of technology transfer within TKK, these innovations have been successfully transitioned to Neuromag.

The navigated Transcranial Stimulation System is also outstanding. The technical goal to measure EEG right after a TMS pulse was most challenging and really solved by the group at TKK. Major contributions to understand brain function came from this lab.

The main recognition of the quality of the LCE's research is in the form of winning the national status of Center of Excellence for two six-year periods, 2000-2005 and 2006-2011. The central figure at LCE is Prof. Kimmo Kaski. He initiated during the last ten years an impressively wide range of research projects that use advanced computational methods to study the behavior of complex systems with a large number of degrees of freedom, a major area of current research in modern theoretical physics. The central activity of this group is that of research in the general area of networks. Perhaps the most impressive recent achievement of his group was the 2007 Proceedings of the National Academy of Sciences PNAS paper, done in collaboration with some of the best and most well-known scientists in the field. This paper analyzed a database of mobile phone activity and the resulting network of nodes (phones or individuals) and edges (representing calls between two phones). A very interesting structure of communities arose; these are subgroups of nodes that have strong connectivity within and weak connectivity between them. This 2007 paper attracted considerable attention and has already been cited 35 times. Other important and highly original recent work of this group focused on DNA elasticity (Phys Rev Letters 2008), study of dynamics of correlations in the stock market (Phys Rev E 2003, 84 citations), demonstrating the wide scope of the interests of this researcher. Prof. Kaski is very well known internationally, and has strong formal and informal connections with leading groups in Oxford, Hungary and the USA.

Another excellent member of this department is Prof. Mikko Sams, whose research on cognition, especially activity of the auditory cortex, has made considerable impact. Some of his early papers, written in the early nineties in collaboration with researchers of the

Low Temperature Physics Lab had 200-300 citations; he published more recently (in 2006-7) two papers in the PNAS on the auditory cortex.

4. Scientific Impact of the Unit's Research

Numerical Rating (1-5): **4** Very Good International Level

The scientific impact of a majority of the unit's research is excellent. It is reflected in high level of external funding, securing status of national Center of Excellence, invited talks at international conferences, participation in a large number of EU-funded research projects and networks, participation in international tenure and academic hiring committees.

The BME unit is known worldwide and has recognized leading expertise in multichannel MEG, brain imaging and brain research; they have generated many very creative ideas (e.g. navigated TMS and hybrid MEG-MRI). They wrote many articles in journals with high impact. Ilmoniemi is Fellow of the Finnish Academy of Technical Sciences and has won several prestigious prizes for innovations. In particular, he founded and acted as the head of the award-winning company Nexstim.

The LCE has done outstanding research in the field of modeling complex networks, with a large number of published articles and citations. Kaski is a Fellow of the Finnish Academy of Sciences and of several other international Societies and Academies (American Physical Society, the Institute of Physics UK and Academia Europaea). He has established close research ties with Wolfson College of Oxford University in the framework of an affiliate unit there, which he heads.

Another member of the faculty, Mikko Ensio Sams, comes from a very different scientific back-ground; he is a well-known expert in brain research, and has very high international standing and visibility. His group has also produced a large number of articles published in leading journals that generated considerable international impact.

5. Societal Impact of the Unit's Research

Numerical Rating (1-5): **5** Outstanding International Level

The societal impact is excellent, with remarkable contributions to health, education, industry and technology. The TKK through the BME was a partner in setting up the BioMag Laboratory at Helsinki University Central Hospital, which is a leading center for magnetocardiography (MCG), magnetoencephalography (MEG), and transcranial magnetic stimulation (TMS). Some of these technologies have already been put to clinical use, and are applied under several clinical conditions for improved pre-surgical mapping.

Six spin-off companies have successfully been founded with participation of BECS. Some of the research in MEG is now done in collaboration with Elekta. In the period of 2003 to 2008 in total 10 Tekes projects have been granted in collaboration with Finnish industries.

BECS has made significant contributions to education. In particular, the work and activities of Prof. Sams, via the CICERO learning network, aim at improving quality of education. The interdisciplinary and interdepartmental study program on Bioinformation Technology is attracting outstanding students.

Brain research is a topic that can – in addition to scientific journals – be reported in newspapers, magazines and in TV, and the group is obviously quite active in this respect.

6. Research Environment at the Unit of Assessment

Numerical Rating (1-5): **4** Very Good International Level

At the moment the available space and facilities are not optimal. In October 2009, however, BECS will move into a building that is being renovated; this building will provide (according to BECS researchers) an excellent research environment that suits the Unit's needs. The building will contain many biophysics and electrophysiology laboratories including a magnetically shielded room for the hybrid MEG-MRI project.

In addition to the available excellent on-campus instrumentation, the group has access also to the BioMag laboratory including MEG, EEG, MCG, ECG and TMS facilities. Also the Advanced Magnetic Imaging AMI Centre can be used by BECS.

For the CoE "COSY" a state-of-the art cluster computing and data storage facility is available. The group has access to several fairly unique databanks, such as patient data at Helsinki University Central Hospital, to be used for medical research, a large database of international stock markets that is used for studies in economic modeling and a unique bank of mobile phone data which has already been used for research on communication networks and social networks.

Members of the Faculty feel that there is a strong need for expansion. They plan to nearly double the size of the senior research staff. We were informed that a new Professor, Paavo Kinnunen from the University of Helsinki is expected to join BECS in 2010. His expertise in medical biochemistry, nanoparticles and molecular imaging will strengthen the Unit at areas where expertise is currently lacking.

Concern was voiced regarding higher than desired teaching load. The panel feels that perhaps some of the specialized courses taught by members of this unit could be consolidated, providing more depth and reducing the teaching load at the same time.

7. Future Potential of the Unit of Assessment

Numerical Rating (1-5): **5 Outstanding**

The two main research areas of BECS have bright future with many interesting options. Information and Communication Technology and Computational Science are at the forefront of modern research and at the frontier of education, information acquisition and dissemination in our fast-changing society. The field of Complexity Science is attracting prominent researchers, world-wide, from different scientific areas. Many of the research topics studied by the LCE are among the most promising and exciting interdisciplinary areas, on the interface between physics, social sciences, computational science and biology. Using the telecommunications networks as a model laboratory for studying the emergence and dynamics of social networks is an original idea that was pioneered by the LCE. Support for continued high quality work is guaranteed by an EU-funded project, coordinated by the LCE.

The panel supports the drive for hiring new research staff with expertise that complements the existing ones. We do recommend that the proposed hiring be done, especially on the LCE side, in the context of a carefully defined strategic plan that takes into consideration projected future projects and research topics. This strategic plan should take into account University-wide long-term strategic planning; for example, if expansion in the direction of Life Sciences is planned, this unit should expand in the direction of Systems Biology, Bioinformatics and Computational Biology.

The hybrid MEG-MRI system under development is a unique project. It is high-risk research, but the group at BME clearly has all prerequisites to solve the challenging problems. We view this project as a potential flagship of future cutting-edge technology at Aalto University. It will provide yet another unique tool for brain research, giving Aalto University brain research world-class advantages.

Health and societal well-being is at the focus of the SHOK project, a strategic initiative in Finland in which BECS plays a leading role. Finally we commend the leading role of BECS in the successful proposal aivoAalto, in the exciting novel field of Neurocinematics. This project is unique in the world in the synergism that puts a cinematographer in collaborative creative contact with neuroscientists, who can influence the film that is to be produced, so that it reflects the needs of the research question that is posed.

8. Panel's Recommendations for the Future

The panel highly appreciates the productivity and creativity of the unit. The panel recommends strengthening the two main activities of BECS, namely instrumentation and algorithms for brain research on the one hand and the Computational Science on the other. We encourage establishment of even more bridges between these two roads. The integrated structure has not yet been fully realized and could be improved, e.g. by a joint seminar series.

Some activities at the BECS do not seem to have strong connections with the rest of the Unit. For example, the work on quantum dots might benefit from being moved to either Applied Physics or to the Micro and Nanoscience unit.

The relationship of BECS with the Brain Research Unit at the Low Temperature Laboratory (T5300) should be carefully considered. There is considerable overlap between the past achievements and technologies and methods used by the two groups. At the same time, there are also significant differences in emphasis and approach. For example, the BECS maintains a very high level of development in both instrumentation and software, whereas the BRU at LTL focuses mainly on fundamental brain research. The panel feels that collaboration between the groups would be beneficial. This could take the form of technology transfer as well as frequent joint seminars. A potential future merger between these groups is a possibility to consider.

Finally we mention here briefly the need to take strategic decisions, on the University level, concerning establishment of a program in Life Sciences at Aalto. Members of BECS should take a central role in this decision making process, if and when it takes place. Long-term strategic planning of BECS will be strongly influenced by the University-level decision on this matter.