Higher Education Quality Assessment Center of Estonia

Evaluation Report

Research evaluation in information technology and systems engineering in Estonia

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1. Introduction

The subject of this evaluation report is the research in information technology (IT) and systems engineering at University of Tartu and Tallinn Technical University in Estonia. Information technology and systems engineering is a very wide area ranging from semiconductor technology and chip design at one extreme, over electronics, computer science, software engineering, and automatic control, to applications in biomedical systems and large scale information systems at the other extreme. This makes an evaluation of this type particularly difficult. The topic is so wide that it is impossible for a single individual to cover it all. The evaluation team consists of four members: Prof. Karl-Erik Årzen from Lund University, Sweden, Prof. Janis Grundspenkis from Riga Technical University, Latvia, Prof. Kai Koskimies from Tampere University of Technology, Finland, and Prof. Peeter Normak from Tallinn Pedagogical University, Estonia. The expertise of the evaluation team lies within the areas of automatic control and real-time systems, artificial intelligence and systems engineering (systems theory, analysis and design), software engineering, and theoretical computer science and didactics of informatics. Hence, not even the team as a whole has technical expertise covering the entire area.

The subject of this evaluation is four different academic units: the Department of Information Technology (DIT) at the Center for Strategic Competence (CSC), Tartu, the Institute of Computer Science (ICS), University of Tartu (UT), the Faculty of Information Processing (FIP) at Tallinn Technical University (TTU), and the Faculty of Systems Engineering (FSE), TTU. The evaluation does not cover the whole IT-related research in Estonia. In a previous evaluation in April 2000, the Institute of Cybernetics at TTU and Cybernetica Ltd in Tallinn were evaluated separately; research done in Tallinn Pedagogical University deals mainly with didactics of informatics and belongs to educational sciences. The research group working at the Computer Center of Tallinn Technical University was not proposed to be evaluated. They are therefore left out fom this evaluation.

The evaluation report is structured in the following way. Section 2 contains some general observations concerning the current situation for Estonian research in IT and systems engineering. The evaluation of the two Tartu-based groups is contained in Section 3. Today at TTU the departments within IT and systems engineering are divided into two faculties in a not so very logical way. The reason for this is partly historical and partly due to personal conflicts. Work on integrated circuits is performed within both faculties. The same situation exists for signal processing, microwave engineering, and for agent-based software technologies. The following evaluation should be read in light of the current situation. Some suggestions for improving the current situation are found in Section 6. The evaluations for the two TTU-based faculties are contained in Section 4 and Section 5. Finally, Section 6 contains our general recommendations and conclusions for the two involved universities and for Estonian research funding agencies.

In most cases evaluation grades are given for the individual research groups or chairs. However, in some cases several groups or chairs work tightly together or have chosen to

report their research as a single unit. In that case the evaluation grades are given for the total research unit, e.g., a department. The evaluation team has used the following criteria as the basis when assigning grades. The grade ***Excellent*** is used for research units that have a very strong international publication record, have good participation in the international research community, have generated several completed PhD theses and have several in progress, have a strong group, and where the future prospects for the area are good. The grade ***Good*** is used for research units that have showed continuing high-level international publications, have some participation in the research community, have generated at least one completed PhD thesis and have several in progress, have a strong group, and where the future prospects for the area are good. The grade ***Satisfactory*** requires that the group have some international publications, although on a weak level. Interval grades are given. The grade ***Good to Satisfactory*** is better than ***Satisfactory to Good.***

2. IT-related research in Estonia

The situation for IT-related academic research in Estonia today is to a great extent decided by factors that are outside the control of the involved research institutes and research leaders. The main such factor is the current economical situation in Estonia, caused by its rapid transition from Soviet-control to a western-style, democratic country. The major result of this is a large difference in salaries between universities and industries, at all levels from MSc students to professors. Due to this it is very difficult for the universities to keep their current staff and students and to recruit enough students for post-graduate studies. The situation is particularly alarming at the student and young faculty staff level. The result is a large average age of university staff, low student intake at master and PhD level, and a large rate of students that drop-off from their studies before graduation. If the current situation remains the situation at the universities will rapidly become unmanageable.

The economical situation also has other effects. It forces the majority of the masters and PhD level students to work in parallel with their studies, in many cases to a very large degree. This extends the study period and decreases throughput. The need for extra income sources is also seen at senior staff level. Many university departments have created spin-off companies that remain affiliated with the department. This is, of course mainly positive, since it makes it possible to rapidly transfer research results to industry. However, in many cases the boundary between the companies and the department is vague, e.g., with respect to economy. It is also common that senior staff work part time for the companies. In the long run this has serious consequences for their basic research competence.

The strong involvement with companies at the student level also affects the nature and topics of the research. Since the companies to large degree finance the studies they, quite naturally, want to have influence on the research topics. This favors research that is directly commercially applicable, i.e., applied research rather than basic research. A sound research environment should contain a balance between applied and basic research. It also favors research in areas that are “hot” or with a large amount of “hype”. It thus

becomes even more important to use the correct buzzwords to describe the research. The only possibility to continue to do basic research is either to find students that are very theoretically inclined, to work in areas without direct current interest for Estonian industry, or to have a strong enough research network and position that allow finding external, e.g., international, funding sources and to use this to improve the financial situation of the students. The latter is a very difficult task. The situation is particularly serious if the governmental funding system gives priority to basic research over applied research. In the worst case it may lead to a situation where Estonian funding agencies give money to research that is relevant from a scientific perspective, but totally irrelevant to the Estonian society and industry.

The lack of research funding also has other consequences. It makes it difficult to travel, thus limiting contributions to international conferences and making it difficult to maintain an international contact network. This decreases the number of international publications, often the number one criterion in research and proposal evaluations, thus making it even more difficult to obtain research funding, especially from EU. Very often the level of research infrastructure does not so much depend on the scientific quality of researchers as on their abilities to attract investors from outside the university.

3. Evaluation of IT research at University of Tartu

The evaluation is based on the self-assessment reports given to the experts prior to the visit, completed with the information given during the on-site visit on November 21, 2000. The reports provide the basic facts necessary for the evaluation.

During the visit, Dr. Merik Meriste gave an overview of the research at the Department of Information Technology at the Centre of Strategic Competence. He also presented the basic ideas of the work on attributed automata and multi-agent technology. Dr. Koit summarized the research work at the Institute of Computer Science, followed by more detailed presentations concerning individual research areas: data security, programming languages and sketchy programming. After the presentations the natural language processing group and the computer-assisted teaching group demonstrated their prototypes.

3.1 Overview

The Institute of Computer Science (ICS) was established as a result of organizational restructuring in 1993. In 1997, the Centre of Strategic Competence (CSC) was established, with the aim to promote research activities in key technological areas. In the area of information technology, the Department of Information Technology (DIT) is the responsible unit at CSC.

ICS has long traditions in computer science, especially in theoretical computer science and programming environments. More recent research areas include natural language processing, data security and learning environments. ICS has about 15 teaching or researcher positions. The institute is headed by Dr. Mare Koit.

The vision of DIT at CSC is to study information technologies from a broad perspective. Accordingly, DIT has collected researchers from rather diverse areas, like public administration, distributed systems, psychology and computer science. The aim has been to promote interdisciplinary research, a key vision being coined as "information ecologies". Individual research topics include multi-agent systems, computer-assisted learning, distributed computing, economics and ethics of information ecologies, and models of representation of knowledge. DIT has four researcher positions. The department is headed by Dr. Merik Meriste.

In the following, the research areas at ICS and DIT related to information technology are evaluated. We do not evaluate those areas at DIT that have no direct connections to information technology; this concerns in particular modeling of representation of knowledge (psychology), and economics and ethics in information ecologies (economics). This does not mean that such research should not be carried out at DIT but simply that there is no information technology substance in these research areas that would allow this team of experts to evaluate them.

3.2 Institute of Computer Science (ICS)

3.2.1 Computer-aided teaching

The group is led by Rein Prank. The group is practically oriented, aiming at usable computer-aided learning environments. The group has developed software to support computer-aided teaching on various topics, mostly in mathematics. A good example of collaboration between different groups (the spin-off APSProg OÜ and Dept of IT, CSC) is the development of APSTest, based on the ideas of Dr. Prank. The software package allows various kinds of question/answer formats. The tool has been exploited in teaching at the University of Tartu and in a number of Estonian regular schools. The group has been actively co-operating with schools. The group has PhD students but no finished PhD theses.

The main concrete result of the group is the software package for computer-aided teaching of mathematics, already in practical use. The group has also developed web-based simulation game techniques for teaching purposes. Dr. Prank has significant international publications (roughly one per year) in the area of technological support for mathematical education. The group has good international contacts and has been actively participating in the international community. The group has concrete plans to further extend international co-operation.

Evaluation and recommendations

Automated support for teaching has been a fruitful application area for information technology, and this area will probably be important also in the future. The group should

broaden their perspectives to other teaching areas and include researchers from other disciplines (for example psychology and pedagogy) more tightly in their work. The group could also deepen the scientific dimension of the work (especially in the direction of didactics), in contrast to more application-oriented topics.

Overall rating of the research group: **Good to Satisfactory**.

3.2.2 Natural language processing

The group is led by Mare Koit and Tiit Roosmaa. The goal of the group is to develop analyzers for Estonian language. The theoretical basis of the work is an extension of the syntactic and morphological techniques developed for Finnish language at the University of Helsinki. The group has developed fairly well working prototypes for syntactic and morphological analysis of Estonian language, as well as a noun phrase extractor.

The concrete results of the group are working language analyzer prototypes. The group has produced one PhD (2000). For natural reasons, most of the publications are in national or Nordic forums; however, few international publications exist.

Evaluation and recommendations

The work of this group is likely to be significant for Estonia in near future, especially in the multi-lingual EU environment. Although full machine translation is so far not possible, automated natural language processing will have many useful applications and its significance will be increasing. The group has demonstrated its capability with well working prototypes. The group has good contacts especially with the Finnish language processing community and reasonable publication record.

Overall rating of the research group**: Good to Satisfactory**.

3.2.3 Data security

The group is led by Jan Villemson. The group consists of five members from University of Tartu, Helsinki University of Technology and Cybernetica Ltd, the main part of the work being carried out by Cybernetica Ltd. The goal of the group is to develop software solutions to support the new Estonian law on digital signatures. In particular, the group has developed a time-stamping server and a notary server to support the use of digital signatures.

Evaluation and recommendations

The area of the group is obviously important, and the group has done pioneering work due to the early introduction of digital signatures in Estonia. The results are commercially significant not only in Estonia but also globally. The role of the University of Tartu is somewhat unclear since the leading researchers have only part-time teaching positions at the UT. The group has some significant recent publications in international forums. The group is also active in international standardization work.

Overall rating of the research group: Not evaluated (evaluated already in April 2000 as a part of the evaluation of Cybernetica Ltd)

3.2.4 Programming environments

The group is led by Jaanus Pöial, VarmoVene and Jüri Kiho. The main areas of the group are stack-based languages, functional languages and support for program visualization, understanding and editing. The latter topic has been later extended to cover arbitrary structured data.

In the area of stack-based languages, Jaanus Pöial has been actively participating in the international Forth community (for example as a PC member of a major international conference series, EUROForth). This stack-based programming language has a rather limited but devoted community and the language itself is still used in certain applications. However, although the language is conceptually interesting, its significance is diminishing. Dr. Pöial has studied in particular the checking of the validity of Forth programs. The work has been recently slightly redirected towards Java, exploiting the fact that Java bytecode is a stack-based language. Another research topic has been the specification of correct stack-based programs through rewriting rules on sequences of stack operations. The results have been published mainly on workshop-level European forums.

In the area of functional programming, the research has been focused on type theory and categorical logic. In the former area a taxonomy of lambda calculus has been derived, in the latter area the group has studied e.g. various terminating recursion and co-recursion schemes. The group has produced one PhD (2000).

In the area of program visualization and understanding, the work has concentrated on so-called sketchy modeling techniques for programs (Fortran, C++, Java) and structured data. A tool supporting the developed model of structured data has been implemented, and it is being used for teaching purposes at the University of Tartu. The original idea of the tool is to mix textual and graphical information in a way that preserves the conventional textual linear form but still provides (at least partially) the intuitiveness of graphical notations. Future plans include the studying of the possibilities for automated model construction. The work has been published on national level and in Nordic workshops.

Evaluation and recommendations

This group in fact consists of several small individual projects on diverse topics, each with very limited resources. Some of the projects have a long history and they have been tightly coupled with single persons. The publications of the group have remained mostly on the workshop-level, although in some cases there would have been potential for higher-level publications. The main persons of the projects are competent, but their capacity could be better exploited if they formed a joint project with a common goal. The group should reflect upon the significance of the current topics in the context of modern information technology. For example, in the area of sketchy programming the group might consider the use of XML as the basis of the work, XML being the current standard for presenting structured data.

Overall rating of the research group: **Satisfactory.**

3.2.5 Theoretical computer science

This group, led by Mati Tombak, has a long tradition at UT. The area of the group has been computational complexity, algorithmics and combinatorics. A separate subgroup has later joined this group, led now by Olga Sokratova. The subgroup has recently studied semirings, graph algebras and cubic graphs. The group has published its results internationally (about 7 publications in medium-level forums).

Evaluation and recommendations

The research areas do not belong to the most critical ones considering the effect on information technology. However, although some of this work is closer to mathematics than computer science, especially the graph-theoretic work is relevant with respect to potential applications in information technology.

Overall rating of the research group: **Satisfactory to Good**.

3.2.6. Evaluation and recommendations (ICS)

The research activities at ICS are carried out by extremely limited resources, due to the lack of funding. Partly because of this, and partly because of the great number of diverse research directions, none of the current research projects has been able to become a significant group internationally, in spite of the competence of the research staff. The level of research funding is alarmingly decreasing in year 2000 (from approx. 1.3 MEEK to 650 kEEK). In particular, the portion of project funding has dropped from 900 kEEK to 300 kEEK. This trend can cause serious damage to the research activities at ICS.

Regardless of the level of research funding, the institute should increase co-operation internally, between different institutes at UT, and different universities in Estonia, in particular Tallinn Technical University. This co-operation could take the form of joint applications to national funding sources and EU. In this way the resources could be targeted in a more focussed way.

The institute has contacts to software industry, but these contacts should be strengthened. In particular, the institute should look for research topics that are relevant for Estonian software industry, and that can be partially funded by the industry.

The production rate of PhDs has remained relatively low: in 1996-2000 only three PhD theses have been completed at ICS. There should be special efforts for more systematic PhD guidance and training.

There are significant flaws in the infrastructure of the institute. Resources should be especially directed to the basic repairing of the premises.

Overall rating of the institute: **Satisfactory to Good**

3.3 Department of Information Technology (CSC)

3.3.1 Multi-agent systems

The group is led by Merik Meriste. This research direction is based partly on the earlier work by Dr. Meriste in which a new computational model was developed by extending finite automata with attributes and attribution rules, affecting the transitions. This model was used successfully for example for the recognition of ECG signals. A central idea is to apply this technique for specifying the behavior and communication patterns of agents. Multi-agent technologies are becoming a key approach to the technological basis of intelligent autonomous software systems whose global behavior cannot be described in a deterministic way. Such systems are expected to become common especially in the Internet. The group has submitted a project proposal on this topic in co-operation with the Tallinn Technical University. The group has publications on the Baltic level.

Evaluation and recommendations

The area of the group is highly relevant for modern information technologies, but so far no convincing results have been generated. The idea of applying attributed automata is promising. The planned future co-operation between University of Tartu and Tallinn Technical University is very desirable. The group should create contacts to other international groups studying agent technologies and better position their work with respect to other approaches.

Overall rating of the research group: **Satisfactory**. However, the evaluation team would like to stress that this concerns the research in its present stage, and that the future prospects could be promising, especially if collaboration with TTU is established.

3.3.2 High-performance computing

The group is led by Eero Vainikko. The aim of the group is to develop parallel computing methods for high-performance processing, required for example in computational fluid dynamics. The group has close relations with Bath University in UK, and it has produced a few good international publications.

Evaluation and recommendations

The group has rather thin presence at CSC. The work is on a good international level.

Overall rating of the research group: The evaluation team decided not to grade this research group. The PhD level work was mainly performed in Norway and currently Eero Vainikko is at Bath University. Hence it is questionable whether it, from a research point of view, should be considered as a part of DIT.

3.3.3 Evaluation and recommendations for DIT

It seems that the aim of producing interdisciplinary information technology research by bringing together persons from diverse areas has not been realized so far. There is no indication of research results that would involve more than one person of the different subareas. It seems clear that without more concrete plans on common research goals such co-operation will not take place. Since the resources of both ICS and DIT are limited, the

research efforts at these sites should be coordinated so that they support each other and if possible, aim at common goals.

The research funding of DIT is dropping in year 2000 from the level of approx. 1 MEEK to 800 kEEK. At the same time, development activities at DIT have been financed from these resources as well, due to the lack of separate funding for basic infrastructure. We consider this as an unhealthy direction. At the moment, most of the research funding comes from long-term targeted government funding, whose existence is vitally important for DIT. DIT should considerably intensify the efforts to get funding from Estonian Innovation Foundation and EU.

Overall rating of the department: **Satisfactory**.

4. Evaluation of Faculty of Information Processing, TTU

4.1 Overview

The expert team visited Faculty of Information Processing on 22 November 2000, according to a prepared agenda. The team was given the following materials:

- Self-Assessment Report (94 pages)
- Additional materials (presentation slides, copies of several papers, etc.)

The team discussed presentations given by the following members:

- Prof. Jaak Tepandi gave a general overview of the faculty of Information Processing
- Assoc. Prof. Margus Kruus, director, gave an overview the Department of Computer Engineering
- Assoc. Prof. Rein Kuusik, director, gave an overview of the Department of Informatics
- Prof. Andres Taklaja, director, gave an overview of the Department of Radio and Communication Engineering

In order to get a better view of the activities the team also visited the departments. Presentations of selected projects and demonstrations were given at each of the departments.

Firstly, the team would like to point out the following basic facts:

- Faculty of Information Processing was established in 1996 as the result of the reorganization of Faculty of Computer and Systems Engineering
- The faculty has three departments (called also Institutes) and one centre: Department of Computer Engineering, Department of Informatics and Department of Radio and Communication Engineering. Rehabilitation Center (SEN-Center) was founded in 2000
- The faculty has a detailed development plan for the period 2000-2004 containing also a SWOT analysis

?? There are good internal relations inside the faculty but no tight scientific contacts between the groups

The detailed descriptions of the departments and projects are given in following sections.

4.2 Department of Computer Engineering

The department of Computer Engineering (DCE) was established in 1967. DCE has three chairs (Computer Engineering and Diagnostics, Digital Systems Design, Systems Programming). Academic staff consists from 2 professors, 10 assistant professors, 3 lecturers and 5 researchers. DCE delivers over 50 courses for students of diploma, bachelor, master and doctoral levels in the study field "Computer and System Engineering". Basic funding of research and development in 2000 is 1,32 mEEK.
Basic research areas of DCE are design and diagnostics of digital systems. Prof. Raimund Ubar, head of the Chair of Computer Engineering and Diagnostics, gave a detailed presentation of research and development in the area of diagnosis and testing of digital systems. He points out the following main research fields: decision diagrams, test pattern generation, simulation of circuits and systems, and design error diagnosis. Results in the field of decompositional design were presented by Assoc. Prof. Peeter Ellervee (Chair of Digital Systems Design). The team has not evaluated the research and development activities of the System Programming Chair since this group has been already evaluated in April 2000.

The research activities of the department have a rather long history going back to 1970. It provides continuity of the research topics. The group has high competence and is very active and successful in applying for funds and grants (about 25 research and development projects during last five years, 144 publications, and co-operation with 20-30 universities). The group has developed a novel diagnostic model for digital systems based on decision diagrams, a new hierarchical approach to test generation, methods and a set of tools for test generation and fault simulation, new analysis and partitioning methods for hardware/software codesign used in designing of cryptographic processor ASICs.

The research activities are connected with post-graduate studies – 4 PhDs and 7 master theses have been defended in this group. Currently there are 4 projects supported by Estonian Science Foundation, 1 COPERNICUS projects and 5 joint bilateral projects. Four PhD students are involved in these projects at the present moment. It is worth to stress that all students are working full-time on their theses at the department, which is not the case with other evaluated groups. The group has applicable outputs and, as a consequence, good perspectives to implement the obtained results. Unfortunately, at this moment there are not any industrial and marketing activities.

The evaluation team had the opportunity to meet PhD students, visit laboratories and to get acquainted with equipment and software used in teaching and research as well. All facilities correspond to the needs of the group.

Evaluation and recommendations
The group has novel results from research and development. The quality of research and development corresponds to the international level. The group is very successful in applying for funds and grants, and have broad international co-operation. The number of publications in high level international conference proceedings and journals (including joint publications with foreign scientists) is very large, however most of this is due to Prof. Ubar himself. The group has rather high potential of young researchers and good perspectives. The evaluation team recommends the group to put more efforts in productifying the obtained results.

Up until now the group have had no interaction with Estonian industries, mainly due to the nature of their research topic. However, recently collaboration has been established with Artec Design Group. This company also has connections to the US market. Cooperation with local industries is important in order to get funding from EU sources, therefore this new collaboration is important for the group. However, it also increases the risk for brain drain from the group.

Overall rating of the department: **Excellent**.

4.3 Department of Informatics

Department of Informatics has been founded in 1992. The department has 4 chairs (Information Systems, Software Engineering, Foundations of Informatics, Knowledge-Based Systems) and 2 spin-off firms of TTU – Komptuur Ltd. and Index_Net Ltd. Ass. Prof. Rein Kuusik, director, who gave the survey of the department, pointed out that a large number of teaching staff and students have left for industry during recent years. The overview of research and development in the department was given by Prof. Jaak Tepandi. The staff of research and development during the period is as follows: 1 DrSc, 6 PhD, 12 MSc. Basic funding is 345 kEEK. The characteristic feature of research and development activities is a wide variety of research topics (no good focused research direction can be defined). To some extent three main directions can be listed: knowledge-based systems and software quality management (supervised by the Chair of Knowledge-Based Systems and the Chair of Foundations of Informatics), software engineering (supervised by the Chair of Software Engineering), and information systems (supervised by the Chair of Information Systems). The group has achieved the following main results: new testing and auditing methods for distributed uncertain knowledge based systems, a novel approach to knowledge based software testing, a new agent-oriented methodology for modeling, design and business information systems, and a global electronic commerce methodology have been developed. The department is active in establishing contacts with industry and carries out several very application oriented research projects. This may cause a decrease of the basic research competence level in the future.

The research activities are connected with studies – 4 PhD and 33 master thesis are defended in this group. Nine PhD theses are in progress. Currently there are 2 projects

supported by Estonian Science Foundation, 1 TEMPUS project, and 1 PhD grant. The group has 67 scientific papers, of which a large part is local publications.

The following topics were presented to the evaluation team;

?? Agent-oriented methodology for the modeling, design and implementation of business information systems (Kuldar Taveter)
?? Information system self-development in virtual learning organizations (Mart Roost)
?? Multimedia learning and communication (Assoc. Prof. Jaak Henno)
?? Internet as a tool for rehabilitation (Assoc. Prof. Kaido Kikas)
?? Buyers decision support system (Assoc. Prof. Enn Õunapuu)
?? Monotone system theory, overview of PhD and MSc thesis work (Prof. Emeritus Leo Võhandu)

Research focused towards development of agent-oriented methodologies matches the hot topics of AI and is intensively investigated at the international level. This is a very promising direction for the group that may lead to the defined goal of the research: elaboration of methods and tools for analysis, design, implementation and quality management of large distributed and knowledge-based systems with complex structure, semantics and behavior. In this context, research in the field of distributed knowledge-based systems is relevant for the group. The competence of the research group in the above directions is high.

Several small teams are working in the field of e-commerce and Internet applications. Research in this direction is very strongly application driven. E-commerce is needed by Estonian industry and that may cause problems to form a really strong research team without danger to quickly loose the students.

The evaluation team had the opportunity to meet PhD students, to visit laboratories and to get acquainted with equipment and software used in teaching and research as well. All facilities correspond to the needs of the group.

Evaluation and recommendations

The department has novel results from research and development. The quality of research and development partly corresponds to the international level. The group is not successful in applying for funds and grants. On the other side the group has strong contacts with industry and good innovative experience. The results are applied in various fields of Estonian economy and industry. International co-operation is not intensive enough. The number of publications in high level international conference proceedings and journals (including joint publications with foreign scientists) is relatively small (11 out of total 67). The group has rather high potential of young researchers but the present structure of research activities implies a high risk to loose young researchers. The evaluation team recommends the department to define a research and development strategy that allows synergy effects from research in various fields, and to create an environment where most of the staff can participate in research and development.

Overall rating of the department: **Good to Satisfactory**.

4.4 Department of Radio and Communication Engineering

The Department of Radio and Communication Engineering (DRCE) was founded in 1965. There are 5 chairs (Radio Engineering, Telecommunications, Microwave Engineering, Signal Processing, Communication Equipment). The research staff consists of 3 professors, 1 Prof. Emeritus, 3 Ass. Professors, 6 researchers, 1 PhD, and 1 engineer. Research is concentrated in the following fields: signal processing methods and algorithms used in telecommunications and design of various kinds of telecommunication equipment, in particular, special filters. Results have been applied in many fields of telecommunication and sonar technology. Estonian Maritime Board hydrographic ships were equipped with ecologically safe, precise sonars for measurement of sea bottom profiles. The group funding is 292 kEEK. The research is rather weakly connected with teaching. Only one PhD theses and nine master theses have been defended during the period. That is why the DRCE is the "oldest" department (average age is 49 years). The group has published 50 papers (large part is published in Estonia and other Baltic countries). Currently there are 1 project supported by Estonian Science Foundation, 5 applied research projects, and 4 Innovation Foundation projects.

The research at the Chair of Radio Engineering was presented by Prof. Ants Meister. The activities are focused on measurement systems in radio engineering, applications of digital spectral analysis of multi-channel signals, signal classification algorithms, and applications in communication and biomedical engineering.

The research activities at the Chair of Telecommunications were presented by Ass. Prof. Avo Ots. These activities are related to new methods and technologies in telecommunication with focus on multimedia transmission over the GPRS network. The latter is done in collaboration with Ericsson.

The research at the Chair of Microwave Engineering was presented by Prof. Andres Taklaja. The main field of research is the design of microwave equipment. The chair has long time experience in military atmospheric optical communication link design. The spin-off company Rantelon Ltd has been established.

The research at the Chair of Signal Processing was presented by Prof. Ilmar Arro. New complex sonar signals have been investigated. A number of precision sonars for sea ground mapping using digital signal processing have been developed and put into production.

The research at the Chair of Communication Equipment was represented by Prof. Vladimir Heinrichsen. The research activities are connected with the needs of Estonia in the field of standardization and testing of telecommunication equipment being imported to Estonia or designed and produced locally.

Evaluation and recommendations

The department has novel results from research and development, but they are very application driven. The topics in the field of biomedicine overlap with research topics of other groups at the Faculty of Systems Engineering. The department has not been successful in applying for funds and grants, and has a rather high average age of the research staff. The department as a whole has strong contacts with industry and good innovative experience. The results are applied in various telecommunication areas. There is no international co-operation in basic research. The number of publications in high level international conference proceedings and journals (including joint publications with foreign scientists) is relatively small (only 2 among the 39 most important publications reported). The group has no significant potential of young researchers.

A general problem for the department is the small number of students and the small number of generated theses. For all the groups it is difficult to see what the real research problems are, especially so for the Chair of Communication Equipment. The evaluation team recommends the department to define a research area, which can promote international contacts and reach an international level in future.

The department covers the full span from radio engineering using microwave technology to telecommunication. In order to meet the future demands of Estonia we recommend the department to put more focus on the telecommunication part. The radio engineering and microwave work has strong connections to the work that is being done at the Dept of Electronics and at the Biomedical Engineering centre. We recommend the department to establish cooperation with these groups.

Overall rating of the department: **Satisfactory to Good**.

5. Evaluation of Faculty of Systems Engineering, TTU

The evaluation of the Faculty of Systems Engineering, TTU took place on November 23. The input to the evaluation was a self-assessment report of 220 pages containing the required information about the faculty. The report was very informative and well structured containing, e.g., very detailed development plans and SWOT-analyses. In the report all statistical information is gathered for the period 1994-2000. In order to be able to compare with the other research units subject to evaluation we have decided to only consider the statistics for the period 1996-2000.

The evaluation started with a one-hour general presentation of the faculty and a following discussion. After that the two departments and the biomedical engineering centre presented their activities for two hours each. The evaluation ended by a concluding discussion with representatives for the faculty.

5.1 Overview

The Faculty of Systems Engineering consists of three units: Department of Computer Control, Department of Electronics, and Biomedical Engineering Centre. In addition to this the faculty also contains the Electronics Competence Centre, but since this centre has no research obligations it is excluded from this evaluation. The dean of the faculty is Professor Leo Mõtus.

The aim of the faculty is to perform research in IT as used and required for design and implementation of embedded computer applications. The major research areas are theoretical and practical aspects of systems modeling, design and software development, methods and tools for electronic design and system development, and modeling, monitoring, and control of natural and artificial phenomena and processes.

The faculty consists altogether of 11 professors, 7 assistant professors, 4 lecturers, 6 senior research assistants, 12 research assistants, and 7 assistants.

5.2 Department of Computer Control

The Department of Computer Control formally consists of five chairs: real-time systems, automatic control and systems analysis, circuit theory and design, automation and process control, and theoretical informatics. However, the chair for automation and process control has been vacant so long that the group has practically ceased to exist as a separate unit. The chair for theoretical informatics is a part of Institute of Cybernetics and is therefore not considered here.

The core research of the department has its origins in automatic control and automation, with the exception of the chair in circuit theory and design that has stronger connections to general electrical engineering.The director of the department is Professor Ennu Rüstern.

The following presentations were given: a department overview (Professor Ennu Rüstern), overview of real-time systems group (Professor Leo Mõtus), overview of automatic control and systems analysis group (Ennu Rüstern), presentation of the work on fuzzy modeling (Andri Riid, researcher), presentation of the work on power network management (Taivo Kangilaski), overview of the circuit theory group (Professor Vello Kukk). After that followed a tour of the laboratories.

5.2.1 Real-Time Systems Group

The real-time systems group is headed by Professor Leo Mõtus. The research has so far mainly been focused on development of formal timing models for real-time software systems. The work has resulted in the Q-model and the associated Q-methodology for specification, simulation, and verification of timing properties. This development has been performed in collaboration with Prof. Mike Rodd's group at University of Swansea.

The work has also led to the development of LIMITS, a CASE tool realizing the above model. Some efforts have also been made at aligning the Q-methodology with UML and Real-Time UML.

For the future the group plans to somewhat change direction moving into multi-agent systems building upon the existing competence in real-time systems, distributed control and machine learning. The intention is to partly do this in collaboration with Prof. Merik Meriste from Dept. of IT, CSC, Tartu.

The research group has generated one spin-off company, IB Krates. The main activities of IB Krates are concerned with the LIMITS tool and general consulting in the process control area.

Evaluation and Recommendations

Embedded systems and embedded control systems is a niche area that most likely could be important for Estonian industry. It is also currently an important area worldwide, with the current emphasis on distributed and mobile systems. The ambition of Mõtus is to apply for a Center of Excellence in Embedded Computer and Communication Systems. This appears to be a very good initiative.

The research performed so far on the Q-model is well motivated and of high relevance. More efforts could perhaps have been put on spreading the approach outside the real-time control community, e.g., to the IEEE real-time systems community. However, the resources have not allowed that.

In order for the new direction on multi-agent systems to be successful it is important that collaboration is established with the Department of Informatics at Faculty of Information Processing where strongly related activities are being performed.

Professor Mõtus is well recognized in the international real-time control community. He is also active in organizing workshops, in participating in editorial boards etc. As a result of this he has quite a lot of international contacts. For the period 1996-1999, 3 journal articles and 8 conference publications are presented. Of these almost all are in respected international contexts. No figures were presented for year 2000. Hence, from a publication perspective the group performs well. However, most of this is due to the personal work of Mõtus.

The funding situation for the group also appears to be good. The research funding comes from several sources, e.g., ESF, EU projects (Esprit and Copernicus), Estonian Innovation Foundation, and through contracts with IB Krates. Especially notable is that the group, as a university group and through IB Krates, has succeeded to become a member of an accepted EU Fifth Framework project, MINICON.

The major problem with the group is its poor success in attracting students and, hence, few generated theses. The group is also very small in size (two full-time senior staff, two

MSc students, and one PhD student). In the period 1996-2000 five MSc theses and no PhD theses have been generated.

Overall rating of the group: **Good**.

5.2.2 Automatic Control and System Analysis Group

The Automatic Control and System Analysis Group is headed by Professor Ennu Rüstern. The self-assessment report lists the following research activities:

- Transparent fuzzy modeling for control
- Modeling of multirate multivariable control systems
- Robust control
- Event Navigator – a network analysis tool
- Tracking and Identification of dynamical systems

The work on robust control is performed together with Institute of Cybernetics and has already been evaluated in that context.

The work on fuzzy modeling focuses on fuzzy modeling techniques that preserve transparency or readability. Different constraints on membership functions are introduced that allow transparency to be maintained during automatic data-based identification and tuning. In the beginning Mamdani-type models were considered, but now the work has been expanded also to Sugeno-type systems. Applications in fed-batch control systems are reported. A researcher/PhD candidate (Andri Riid), together with Prof. Rüstern, perform the work.

Multi-rate control systems arise naturally in the context of distributed and decentralized control systems. The current research is based on state-space approach. Several different types of models have been studied. A design methodology has been developed and methods for handling systems composed of a “fast” and a “slow” part have been defined. The work has been performed by I. Astrov, who presented a PhD thesis on the subject in 2000.

The work on the Event Navigator was initiated by the Estonian Power utility Eestie Energia Ltd. The work is performed by Taivo Kangilaski who also works for the utility. The aim is to develop a control and monitoring system for joint operation of power stations, the national electricity grid, and distribution networks in Estonia. The work is very applied in nature.

Prior to the above work Taivo Kangilaski was involved in project on tracking in connection with air traffic control. The tracking system receives data from several geographically distributed radars. Based on this the system should establish a single route for the object. Also this work was very applied in nature and performed in connection with a company, Virumaa Tiivad AS.

Evaluation and Recommendations

The work on fuzzy modeling is quite specialized. One could debate whether transparency really is a necessary requirement for fuzzy control systems, especially when they are derived from data. The fuzzy control community has not recognized the research performed in the group. Seven publications are reported. They are, however, mostly in local journals or conferences. One conference publication is at a recognized international conference and two at international symposia of minor status.

The work on multi-rate control has generated a large amount of publications (17) and one PhD thesis. However, all of these are in local journals or conferences or at small international workshops of low status.

The work on tracking and network analysis has generated very few publications. The focus here has been implementation rather than conference and journal publication. It is also difficult to see what the real research problems are, especially for the network analysis project.

Being the only chair at the faculty directly focused on control theory, one would have hoped that the work performed in the group should be more focused on core control topics. Currently the group is very scattered from a research point of view.

Altogether the group has generated 5 journal papers and 22 conference publications 1997-2000 (excluding the work on Robust Control). This is a quite good amount, but the overwhelming majority are either national publications or publications of low international status. We recommend that the group tries to, in the future, publish in more well-recognized international circles.

The theses generated in 1997-2000 consist of 1 PhD and 6 MSc theses. The group contains 2.5 senior researchers with PhD degrees (or equivalent). The 0.5 position is Ülo Nurges who we have considered to, from a research point of view, belong to Institute of Cybernetics. In addition to this the group has one assistant and two researchers with MSc degrees. The group does not report the funding situation.

Overall rating of the group: **Satisfactory**.

5.2.3 Circuit Theory and Design Group

The circuit theory and design group is headed by Professor Vello Kukk. The group has a long tradition in circuit modeling and simulation (the SPADE system). Due to financial reasons this work has been abandoned. Instead the work has been focused on modeling of special tasks not covered by classical simulation software. Main research areas are

- ?? High-Q active filters
- ?? Modeling of oscillators
- ?? Design of ICs for RF applications

The hope for the future is to return to automation of circuit analysis, the topic of an ESF grant application for 2001-2002.

A spin-off company, Analog Design Ltd., was created in 1995 and is currently owned by Micro Analog Systems OY from Finland. The company currently employs three persons from the group. Several research problems are claimed to have been generated from the company. This situation has also led to problems and delays with publication of results due to confidentiality reasons.

Evaluation and Recommendation

It is questionable whether circuit theory and design belongs to a department on computer control. Far more natural connections exist, e.g., to the Department of Electronics or the Department of Radio and Telecommunications Engineering.

The group reports 1 journal article and 12 conference publications. They include a fair amount of international publications, e.g., three IEEE conferences. The group is small, one professor, one associate professor and one assistant. No theses at all are reported although it is stated that some MSc and PhD students work at collaborating companies. In addition to the spin-off company, these also include Nokia Research Center.

Overall rating of the group: **Satisfactory to Good**.

5.2.4 Evaluation and Recommendations

The major problem for the department is the lack of students and small amount of generated theses. The groups are also critically small, making it difficult to bring in large contracts. The group has also suffered excessive brain drain to industry.

The international contact network and publications vary a lot between the different groups from quite good to unacceptable. The internal structure of the department is strange. This is especially the case for the chair on circuit theory and design.

Overall rating of the department: **Satisfactory to Good.**

5.3 Department of Electronics

The department consists of three chairs: applied electronics, electronics design, and electronic measurements. The research areas are the following:

- Theoretical and experimental study of new semi-conductor materials
- Application of the new materials for development of electronic components
- Development of measurement instruments and systems based on synchronous signal processing
- Applications of measurement technology in technical test and diagnostics and in medical diagnosis

In their vision for the future the aim is to additionally also work on electronic realization of large-scale information systems, e.g., radar systems, navigation systems, and traffic monitoring systems, and to develop methods for design of diagnostic systems in medical applications.

The director of the department is Professor Toomas Rang.

The following presentations were given: overview of the department (Toomas Rang), overview of the applied electronics group (senior researcher Andres Udal), overview of the electronics design group (Toomas Rang), overview of the electronic measurement group (Professor Mart Min).

5.3.1 Applied Electronics Group

The group is headed by Professor Vello Männama (ill at the day of the evaluation). The research theme is split into two directions: components – modeling of SiC material and devices (Professor Enn Velmre) and systems – problems of modern microelectronic circuits and systems (Männama). On the component side the research approach consists of the following activity chain: semiconductor material parameter modeling, development of device simulators through implementation of new parameter sub-models, measurements combined with simulation to validate the developed sub-models, and finally, device simulation and design. A number of semiconductor materials have been investigated including silicon, silicon carbide, and diamond. Improved electrophysical parameter models have been developed together with improved device simulators. A novel very fast double thyristor has also been designed. The work has been supported by ESF grants, state budget themes, three Swedish grants, and through industry contracts.

The system-oriented branch has focused on integrated electronic circuits and systems for sensor signal processing. Main research problems include current-mode signal processing, phase-locked loop problems, and different microelectronic circuit theory problems. The phase-locked loop approach has been implemented in several practical designs. The work has been supported by ESF grants, state budget themes, and via an international contract from USA.

Evaluation and Recommendations

The group has produced 7 journal articles and 18 conference publications in 1996-2000. Of these 14 are Estonian publications and the remaining 11 international. Hence, the level of the publications appears to be reasonably good. During this time 2 PhD theses, 2 MSc theses, and 3 diploma theses have been produced. The group consists of four persons of which three are involved in the research. A couple of MSc students and PhD students are reported to be involved in the research. The funding situation for the group appears to be adequate.

The group actively collaborates with the other groups within the department. The number of students currently involved in the research appears to be low or zero. The group

appears to have reasonable contacts with other research groups, e.g., at Uppsala University and University of Manchester. The group also reports industrial collaboration with Noptel OY, Finland, ARSmikro (a spin-off company from the department), Fincitec OY, Finland, and ABB.

Semiconductor research requires expensive equipment. The approach taken in the group is to either build equipment themselves or to collaborate with other groups and borrow equipment. So far this has been possible.

An open question is whether a small nation such as Estonia can afford doing competitive research in semiconductors. On the other hand the country has a lot of know-how in the area from past times.

Overall rating of the group**: Good to Satisfactory.**

5.3.2 Electronics Design Group

The group is headed by Professor Toomas Rang. The topic of the group is design and fabrication of semiconductor devices and ICs, including microsystems. Much of the work is concentrated on wide band-gap semiconductors, especially SiC. Special emphasis has been put on investigations of Schottky and Ohmic metallization technologies for creating substrate contacts. The group claims to be able to produce the largest Schottky contacts for certain types of SiC substrates reported so far. This has attracted interest from international semiconductor manufacturers. Another area where the group has been active is signal processing and microelectronics. An indirect method for measurement of central heating losses in panel houses has been investigated and measurement circuits have been developed. A novel signal processing circuit for semiconductor gas sensor output has been designed. The group has also participated in the work on phase-locked loops performed at other places within the department.

Evaluation and Recommendations

The group has generated 7 journal articles and 18 conference publications in 1996-2000. Of these approximately 11 are in international contexts. The group has not generated any PhD theses. However, three PhD students are in the system. Three MSc theses have been generated and two students are currently within the system. The group consists of two senior researchers with PhD degree, three PhD students, two technicians and two MSc students. The two latter work in industry in parallel with their studies. The group has been subject to drop-offs to industry that has stopped certain research activities. The group has collaborations with Budapest TU and University of Saarland. Toomas Rang also appears to have relatively good European contacts. The group has a contract with the company Clifton Electronics Ltd in Tartu (the employer of one of the MSc students).

The work within the group has strong relations to the two other groups at the department. The work on SiC semiconductors is connected to the applied electronics group, the work on sensor signal processing is related to the electronic measurement group and the work

on PLL systems is related to both groups. This shows good integration between the groups, perhaps so high integration that the three groups really should be considered as a single research group.

Overall rating of the group: **Good to Satisfactory**.

5.3.4 Electronic Measurement Group

The group is headed by Professor Mart Min. The profile of the group is study and development of measurement and data acquisition systems and their electronic and software components. The main research area is lock-in, or synchronous measurement systems and precision PLL systems. Other research topics are design of novel measuring instruments with application in scientific instruments, technical diagnosis, and medical diagnosis, adaptive signal processing algorithms for measurement information extractment, and development of methods for testing of mixed analog/digital circuits and systems. Due to industrial PhD students the group currently also works with GSM-based positioning systems in connection with Ericsson, and with smart house systems in connection with ARTEC. The group has several industrial contacts, e.g., with Fincitec, Micro Analog Systems, Finland, and St Jude Medical Inc (USA/Sweden). The latter collaboration concerns developed of rate-adaptive pacemaker control systems. Here, two Swedish patent applications are pending. The group has a lot of research contacts, predominantly in Germany and Sweden. They have also participated in Copernicus and Esprit projects.

Evaluation and Recommendations

The group consists of 3.5 persons with PhD degrees of which 2.5 are involved in the research. The group has four PhD students of which two have scholarships, and at least three MSc students. The group has generated 2 PhD theses (both during 2000) and 5 MSc theses. In the period 1996 – 2000 the groups reports 10 journal papers and 44 conference publications. Several of the publications are in well-respected international contexts. Hence, the level of international publications is good. The group has a lot of research contacts and industry contacts. The funding situation also appears to be good.

The group has a lot of collaborations inside the department but few outside. A natural collaboration partner would is the Biomedical Engineering Centre which to a large degree has overlapping research interest and common interest with respect to directions for the future. The work on testing have strong connections to the work at the Dept. of Computer Engineering.

Overall rating of the group: **Good**.

5.3.5 Evaluation and Recommendations

The department appears as a well united team with a lot of research topics in common. Better collaboration outside the department at TTU would be desirable. Possible

collaboration partners are the Biomedical Engineering Centre and the Dept of Radio and Telecommunication Engineering where also work on measurements and signal processing in medical applications are being performed.

In order for the department to succeed with its ambition to move towards large-scale information systems it is crucial that the connections to software research groups are tightened. The same holds also for small embedded mobile systems where hardware and software co-design is becoming an increasingly important technology.

Overall rating of the department: **Good to Satisfactory**.

5.4 Biomedical Engineering Centre

The centre consists of two chairs: radio physics (Professor Hiie Hinrikus) and biomedical engineering (Professor Kalju Meigas, absent during the evaluation). The speciality of the centre is bioelectromagnetic systems, in particular interpretation of bioelectrical signals (EEG, ECG, EMG, etc), electromagnetic field interaction with biological systems (e.g., mobile phone effects), and applications of electromagnetic radiation for information gathering about physiological processes and systems. The head of the centre is Professor Hiie Hinrikus.

The following presentations were given: overview of the centre (Professor Hinrikus), microwave radiometry for medical applications (Jevgenij Riipulk), heart rate reconstruction algorithms & analysis of RR and QT dynamics for medical diagnosis (Jaanus Lass), and effects of mobile phone radiation (Professor Hinrikus).

The centre is small. It contains two professors and one part-time associated professor, one full-time and two part-time researchers, and six assistants. The average age of the staff is low (35.5 years) but the head of the centre is close to retirement.

The following are the main research activities and results. Work on microwave radiometry for cancer detection has been going in 1994-1998, partly due to Hinrikus background from the Dept of Radio Engineering. An operational system has been developed that has been used at clinical experiments at a Tallinn hospital. Sensitivity of biological systems towards low-intensive electromagnetic radiation is another current area of the centre. Interesting results have been obtained concerning mobile phone effects. Other areas are coherent laser-based photo-detection for biomedical measurements, non-linear filtering of physiological signals, and evaluation of the quality of different heart rate adaptation algorithms for rate adaptive pace makers. The latter work started in cooperation with the Department of Electronics but was later separated due to collaboration with different industrial partners.

The centre has lots of research contacts, mainly in biomedicine, and contacts with hospitals. The amount of industrial contacts is, however, small.

The location has been a problem for the centre during long time. However, recently new office space has been provided in the building of the Institute of Cybernetics.

Evaluation and Recommendations

The centre has produced 23 journal articles and 24 conference publications during 1996-1999. No figures are given for year 2000. A large amount of the publications are in well-respected international contexts. Two PhD theses have been produced and three MSc theses. Currently two PhD students and eight MSc students are active at the centre. This is quite good in relation to the small volume of the centre. The centre has a lot of research collaborations, e.g., they have been strongly involved in a TEMPUS project, and research contacts, but few industrial contacts. One reason for this is the low number of Estonian companies in the medical and health care area, and the strong dominance of large international companies.

The main dangers that one can foresee for the center concerns the small size of the centre and its, apparent, strong reliance on Professor Hinrikus as a person, especially in light of her closeness to retirement. Another problem for the centre is the lack of collaborations within TTU. Much would be gained if collaboration were established with the Dept of Electronics and with the Dept of Radio and Telecommunication Engineering.

Overall rating of the centre: **Good to Excellent.**

5.5 Recommendations and Conclusions

The evaluation team has identified two major internal problems of the faculty. The first problem is the low number of MSc and PhD students, in some places ridiculously low.
It is crucial for the faculty to very actively trying to improve the recruitment, in spite of the general problems associated with this.

The second problem is the lack of collaboration between the three units. This is particularly evident between the Electronic Measurement Group of the Department of Electronics and the Biomedical Engineering Centre. Both groups work to a large degree with signal-processing and measurement technologies in biomedical applications. In one case, the work related to pace makers, the actual projects are also almost exactly the same. The faculty as a whole would gain a lot if better collaboration is obtained.

6. Recommendations and Conclusions

6.1 Tartu

1. The research between different research groups is not sufficiently coordinated. The evaluation team also got an impression that the Institute of Computer Science does not have any leading researcher who could act as the main promotor of research activities at the institute.

6.2 Tallinn Technical University

The organizational problems concerning the faculties at TTU can be solved in different ways. One possibility is to merge the faculties into a single large faculty, as before the split. A possible name for such a faculty is Faculty of Electrical and Computer Engineering. Such a faculty may also include Power Electronics and possible also some of the Mechatronics activity. Another possibility is to reshape the two current faculties. One possibility would be to have one faculty for computer science and another faculty for IT in engineering. The computer science could contain groups from Institute of Cybernetics, Dept of Informatics, and groups currently at the Computing Centre. The other faculty could include the current faculty of systems engineering, the rest of the faculty of information processing, and perhaps part of the mechatronics activities. Yet another possibility is to totally abandon the rather rigid faculty systems. Instead one could have a flat organization consisting only of fewer but larger departments, consisting each of perhaps 8-12 chairs.

If it is not possible to reorganize the structure it is important that TTU encourages and rewards collaborations over faculty borders, joint research proposals, collaboration in teaching, etc.

Another thing that is striking is how little research on traditional computer science and software engineering that is found within the two faculties. Although part of this can be found at the Institute of Cybernetics it is most likely so that much more is needed in order to be able to produce the amount of software engineers needed by Estonian industry in the future. The share of research in computer science both in foundations of computing (theoretical computer science, discrete mathematics etc) and practical software engineering should be increased.

6.3 General Recommendations

1. The level of financing is by far too low in all categories (studies, targeted financing, grant financing, infrastructure) for ensuring high level results and should therefore considerably increased.
2. The number of Master-level students as well as stipends for them should be considerably increased. The bigger number of Master graduates would create a better basis for selection to PhD studies.
3. It is of vital importance to decrease the gap between salaries for teaching staff at the universities and IT-specialists in industry.
4. There should be created – additionally to the Innovation Foundation – funds for helping to launch production of developed innovative IT products.
5. The status of applied research should be increased in research proposal evaluations by ESF and targeted financing.
6. Cooperation between different universities or faculties should be encouraged through research funding policies.