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# Teaching Dependability Issues in Systems Engineering at the Technical University of Tallinn

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This paper describes the results of co-operation between universities and research institutions from more than ten countries in Europe within the framework of the TEMPUS, EUROPRACTICE, COPERNICUS and ESPRIT programmes. As a consequence of these projects, a new competence centre in the field of electronics and systems engineering was created at the Technical University of Tallinn. A new set of research and teaching-oriented tools, TURBO-TESTER, has been developed and introduced into courses on system dependability issues. The courses are oriented to the concept of *learning by doing*, and to instilling in students problem-solving, teamwork and self-learning skills. An international virtual laboratory is being established to support joint research and co-operative activities in order to increase the quality of teaching.

## INTRODUCTION

During the first years of Estonia's independence, the electronics industry in Estonia has undergone a total reorganisation, along with the birth of many small and medium size companies to meet new market requirements. Small companies are flexible, but they are suffering from a lack of experience and of the availability of modern technologies that are essential for developing competitive products.

Special organisational work has been necessary to develop electronics technology in Estonia, and the university educational and research environment was considered to be one of the most important influencing factors of change. University should prepare people with knowledge of the latest scientific and technological achievements, and graduates should be able to carry fresh potential to research groups and industry.

The rapid development of deep-submicron technology requires a rethinking of present teaching practices in the field of engineering. Silicon is rapidly becoming the unifying medium between traditionally separate disciplines like computing, communication, industrial electronics and software engineering, but co-operation requires the removal of the communication gap between the VLSI education, communication and computer science departments. The objective should be to provide students with a broad education in the analog-digital-hardware-software field, and to instil problem-solving, teamwork and self-learning skills. The only way to reach these targets is an interdisciplinary project-based co-operation between faculty staff from different departments and students. On the other hand, without the active participation of research-staff operating within a close international co-operation, quality of teaching in such a rapidly developing field like electronics and system engineering is not possible.

To meet these goals and to promote R&D and teaching in electronics, computer and systems engineering, a competence centre at the TU Tallinn was established.

## CREATING A TEACHING ENVIRONMENT THROUGH EUROPEAN PROJECTS

Developing an up-to-date environment for research and teaching requires considerable financial resources. The only realistic solution in the difficult economic situation in Estonia was for the TU Tallinn to compete for grants from the EU. Despite the strong competition, the team of the Computer Engineering Department at TU Tallinn has been successful in getting finance for five projects in the framework of European programmes TEMPUS, COPERNICUS and ESPRIT during 1993-1998. As a result of these projects, a Design and Test (D&T) Centre was established with

the objective of providing a professional design environment for interdisciplinary co-operation in electronics design and testing in the field of systems engineering [1]. New teaching and training courses have been developed and implemented. Research and training are carried out in the laboratory in parallel, which has helped to introduce an efficient teaching methodology: l*earning by doing*.

The main consequence of the TEMPUS project was creating a corresponding curricula for digital system design based on ASIC technology, especially on PLD-technology (Programmable Logic Devices) [2]. The problem of high cost involved in the development and application of microelectronics can be solved in Estonia by starting with the implementation of PLD-technology, since PLDs are reprogrammable and entry costs are low, thereby offering SMEs a chance to develop ASIC solutions at very low risk. A corresponding trend can also be observed in western countries where Field Programmable Gate Arrays (FPGAs) are becoming very important. More than 50 students and staff members have been taught and trained at partner universities through the project. Students get hands-on experience in creating ASIC designs by using professional design software not currently available in Estonia; and staff used the opportunity to update and prepare new courses, new laboratory work, and to develop a new CAD technology environment in Tallinn.

Presently, the following design software is installed in the D&T Centre: XILINX and ALTERA for designing PLDs and FPGAs, CADENCE for designing gate-array and standard cell ASICs, SYNOPSYS for high-level synthesis, and other CAD software systems. Most of the very expensive professional design software listed above has been purchased through the support of EC EUROCHIP VLSI Design Action. For investigating different system dependability problems, like fault simulation, test pattern generation, testability analysis, built-in self-test and fault-tolerance quality estimation, an original tool-set created by the staff of the laboratory, TURBO-TESTER, has also been installed on the D&T Centre's computer platform.

## SOFTWARE PACKAGE FOR TEACHING DEPENDABILITY ISSUES

Our society is becoming increasingly dependent on computing systems, and this dependency is especially felt when systems fail. On the other hand, because of the increasing complexity of systems the cost of testing and verification has become a significant part of the total cost of electronic products. It is for this reason that design for dependability, verification and test are becoming more and more important in each of the life periods of a system, in development, production and exploitation, and therefore these issues should also be considered in teaching tomorrow's system engineers.

The curricula in system and electronics engineering should incorporate a greater emphasis on design for testability (DFT) and on the concepts of digital testing. Young engineers should be trained in integrating design and test solutions. Teaching in this domain should be facilitated by using integrated CAD tools that support design verification, testability analysis, DFT, test generation, fault simulation, built-in self-test (BIST), fault diagnosis and fault tolerance.

Traditional VLSI design systems on workstations are both costly and unable to handle large numbers of students simultaneously in educational courses. During recent years, many low-cost tools running on PCs have been developed to fill this gap, usually including the major basic tools needed for IC design: schematic capture, layout editors, simulators and place and route tools. Low-cost systems for solving a large class of tasks from the dependability area (test synthesis and analysis, fault diagnosis, DFT and BIST, especially for teaching purposes) are missing.

An advanced training environment has been developed at the D&T Centre for solving these tasks, and to fill the above mentioned gap. An important component of this environment is a set of tools, TURBOTESTER (TT), which has been created through close co-operation between researchers and students [3][4]. It has been installed on IBM PCs for teaching graduate and undergraduate courses in design for testability and test of digital electronics. TT is an easy-to-learn, easy-to-set-up and low-cost CAD system. It has interfaces to commercially available VLSI design tools such as Cadence, Synopsys, Mentor Graphics, Viewlogic, Compass, OrCAD, ASYL+, Dixi-CAD etc, and includes a large set of tools as implementations of different methods of test synthesis and analysis.

## TEACHING TEST AND DIAGNOSTICS OF SYSTEMS

TT is convenient for teaching issues of dependability in today's digital systems as it offers the possibility to compare different methods and approaches to solving test, diagnosis and fault tolerance problems. It comprises the following important tools: fault simulation, test pattern generation, testability analysis, BIST quality analysis etc, which support design of testable and fault tolerant systems. Different fault models, such as stuck-at, stuck-open and delay faults, can be simu-

lated; different methodological approaches to test synthesis, such as random, genetic or deterministic, can be investigated; different fault analysis approaches, such as simulation-based or deductive reasoning-based, can be used; and different levels of complexity for representing digital systems can be investigated and compared to find out the proper areas or conditions for using.

New laboratory courses, *Diagnostics of Digital Systems* and *Design for Testability*, based on use of the professional design software SYNOPSYS and CADENCE and the diagnostic software TT, have been developed at the D&T Centre and introduced to support teaching system dependability issues at the Technical University of Tallinn. The laboratory work is oriented to giving students hands-on experience in the use of different professional design tools, and to developing the ability to think creatively by forcing students to solve different kinds of non-standard tasks for making a design dependable (fault-tolerant or self-testable), or by forcing them to verify the design, to diagnose and localise faults or design errors. For solving these tasks, different TT research tools are available, but the choice of proper tools is the students' problem. The tasks of laboratory work are formulated as teamwork, where the whole problem will be divided into subtasks to be solved by different team members. The main laboratory concept can be described as *learning by doing*, where the needed skills and know-how are acquired by students themselves during their work. As the staff research and student laboratory work are carried on in parallel in the same room, consultation, if needed, is continuously available.

The TT based laboratory course has also been delivered to students in Finland (TU Helsinki) and the USA (Michigan State University), and it was highly appreciated by students because of the interesting, creative and research intensive exercises. The TT software has also been used in Sweden at several universities for teaching students and for training engineers. Presently, preparatory work supported by the EC is being undertaken for dissemination of this software to other universities in Europe.

## EAST-WEST INTERNATIONAL VIRTUAL LABORATORY

A new European project within the framework of the COPERNICUS programme is being launched to create a Virtual Laboratory for co-operation in research, teaching and knowledge transfer in microelectronics design and test between several eastern and western universities and research institutions, such as TU Darmstadt and Institute of Integrated Circuits of Fraunhofer Society in Germany, Linkoeping University in Sweden, Technical Universities in Budapest, Warsaw and Slovak Republic. The D&T Centre will be one of the nodes of this international network.

The main objective of this project is to establish and maintain a Virtual Laboratory (VL) for promoting co-operative research and training activities between partner institutions in the design of dependable microelectronics systems, one of the most dynamically developing application fields today. VL can be seen as an implementation of a research network based on advanced information technologies (Internet, multimedia, CAD).

The VL will offer a new quality in co-operative R&D and teaching by facilitating immediate exchange of information; sharing of software tools and courses developed by partners; enabling joint work on research projects and practical designs; providing access to microelectronics component libraries, benchmark circuits, design examples etc available to partners; and serving as a source of information not only for partners, but also to all other interested persons and institutions, including national industries with a special emphasis on SMEs. For these purposes, Internet based and multimedia tools and organisational procedures will be developed.

Three lines of complementary actions are foreseen: developing the concept and setting up a research network environment; co-operative R&D and teaching/training activities supported by virtual resources of this environment; and making the R&D results visible to the outside world by organising *User Forums* and regularly publishing electronic newsletters. The scientific mission of VL is to address the challenging topics in *Design of Dependable Microelectronics Systems* by joining scientific competence and research efforts from related fields such as microelectronics design, design methodologies, software/hardware co-design, test generation, and diagnosis of design errors for reaching new dimensions in the quality and dependability of tomorrow's computing systems.

As a synergistic result, research activities in directions that have been traditionally separated can now be in the working environment of the Virtual Laboratory, easily unified for achieving more valuable and tested results. International co-operation between partners by sharing tools, libraries, benchmarks, experience and knowledge will multiply the effects that could be achieved by institutions working separately. VL will make teaching and joint research not only easier and more efficient, but also more cost effective.

As the long-term effect of the project, the new opportunities for co-operation associated with the VL will help to stabilise and increase the innovation po-

tential in the CEE countries and strengthen the European position in the application of IT.

## CONCLUSION

The rapid development of deep-submicron technology requires a rethinking of present teaching traditions in the field of system engineering. The target should be to provide students with a broad education in the analog-digital-hardware-software fields, and to instil problem-solving, teamworking and self-learning skills in students. The only way to reach these targets is an interdisciplinary project-based co-operation between faculty staff and students, based on active participation in international co-operation. As a result of several Euro-projects, a new competence centre in the field of electronics and system engineering was created at the Technical University of Tallinn. The contribution of the centre has been the creation of a professional system design environment carrying out R&D at the international level and introducing new courses and teaching methodologies under the idea of joining research and teaching. These actions and developments will continue on a broader international scale, in the framework of an East-West Virtual Laboratory, to find out and apply new aspects of synergism in research and teaching.

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## BIOGRAPHY

Raimund Ubar is a professor of computer engineering at Tallinn Technical University (TTU) in Estonia. He received his MS degree in control engineering from TTU in 1966 and a PhD degree in computer engineering from Bauman Technical University in Moscow (Russia) in 1971. Since 1971 he has been with TTU, first as an associate professor, and, since 1987, as professor. From 1987-1992 he was Head of the Institute of Computer Engineering. In 1993 he established the Electronics Competence Centre at TTU and was head of the Centre until 1996. He has given seminars or lectures in 15-20 universities in more than 10 countries. In 1988 he held the Barkhausen Chair at the TU Dresden. He has worked as a visiting professor at Linkoeping University (1991), TIMA Laboratory in Grenoble (1992, 1997), TU Darmstadt (1993 and 1994), and Politecnico di Torino (1996).

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