LINKÖPINGS UNIVERSITET

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Självvärdering avseende forskarutbildning i Datalogi vid Linköpings universitet

Härmed inlämnas ovanstående rubricerad självvärdering till Universitetskanslersämbetet. Arbetet med framställandet av självvärderingen har organiserats och genomförts av företrädare för aktuell utbildning.

Ulf Nilsson
Dekanus

Universitetskanslersämbetets utbildningsutvärderingar

Självvärdering

Lärosäte: Linköpings universitet
Forskarutbildningsämne: Datalogi (Computer Science)
Licentiatexamen: ja
Doktorsexamen: ja

1. Environment, Resources, and Area: Subject Area

Research and research education in Computer Science at Linköping University started formally in 1975, when the first professor chair in Computer Science in Sweden was established at Linköping (Professor Erik Sandewall, initially with the department of Mathematics). The first PhD thesis in Computer Science was defended in 1977. The department of Computer and Information Science (IDA) was established in 1983, and since then it has been the home of research education in the Computer Science area at Linköping university.

As of the end of 2016, 218 PhD and 252 Licentiate degrees have been awarded in Computer Science, Computer Systems, Technical Informatics, and Natural Language Processing. Currently these four areas are included in the single *research education subject area of Computer Science*, with 43 active PhD students and 48 active supervisors and co-supervisors.

Since 2001 the department has hosted CUGS, the national computer science graduate school, which was commissioned by the Swedish government and the board of education. Currently, 21 PhD students in Computer Science are formally admitted to and partially financed by CUGS. CUGS also finances a large portion of the PhD courses in the area of Computer Science (open to all students, not only those admitted to CUGS).

Research education in Computer Science at Linköping University covers a broad set of topics, reflecting the current status of this research field. *In all of these topics, international level research is conducted by groups belonging to the Department of Computers and Information Science (IDA)*: Algorithms and complexity, Artificial intelligence and robotics (Robotics, Knowledge representation and reasoning, Automated planning, Intelligent and autonomous systems), Embedded systems (Modelling and formal verification, Real-time systems, Hardware/software codesign, Fault-tolerant systems, Cyber-physical systems), Software engineering (Programming languages and environments, Compiler technology, Software process, Requirements engineering, Software testing), Natural language processing/Computational linguistics, Databases and Web information systems (Semantic Web, Ontology engineering, Data integration, Graph databases, Probabilistic graphical models), Security (Software security, Network security, Communications security, E-service security, Critical infrastructures), Distributed Systems and Networks, Wireless and ad hoc networks, Parallel computing, Green computing and networking, Human-centered systems (Computer supported cooperative work, Multimodal interaction, Ubiquitous computing, Public information systems and electronic markets). Given the active research work going on in all of the above directions, appropriate depth and connection at the international level is guaranteed. In this way, we cover topics ranging from fundamental studies of algorithms, computational processes and knowledge representation to the practical application of computer systems and recent developments such as autonomous systems and green computing. The fact that all of the above groups are working together within the same subject area and the same department, under a common coordination of PhD studies, provides a strong environment and guarantees the required depth and breadth of the education.

In this context it is worth mentioning that research education in three other related subject areas is conducted at the department: Cognitive Science, Statistics and Machine Learning, and Design. Interaction with students and researchers from these adjacent areas provides an excellent environment and opportunities for the PhD students to further broaden their education and research horizon.

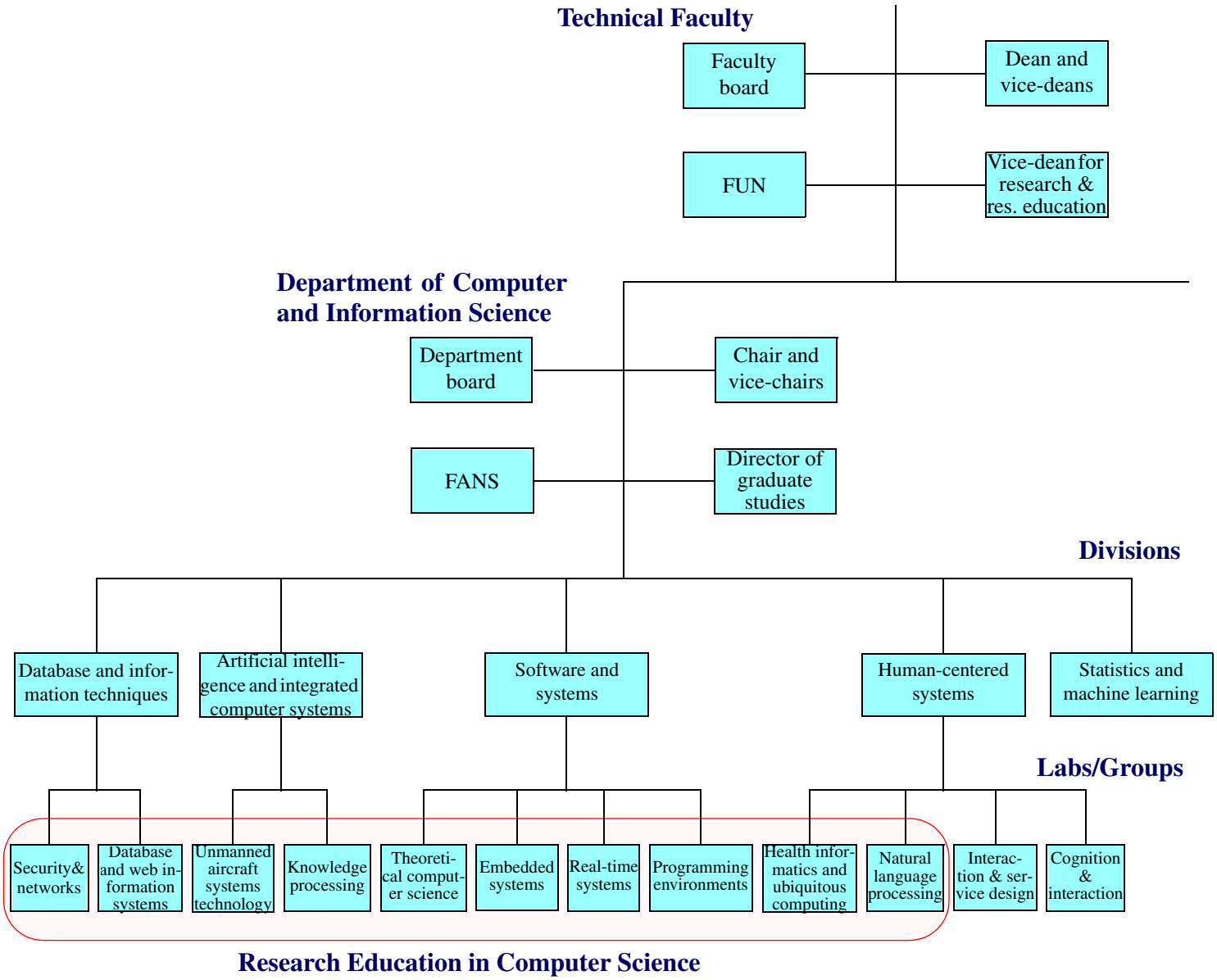

Figure 1. Organization of research education in Computer Science

1.1 Organization

PhD education at the Department of Computer and Information Science falls under the overall responsibility of the Department Chair and is coordinated by the Director of Graduate Studies, supported by a Graduate Studies Administrator.

Research education at Linköping University is coordinated at the Faculty level. For the subject area of Computer Science it is the Technical Faculty that is responsible. The Faculty Board approves the general study plans for each subject area. Under the Faculty Board, a dedicated *Faculty*

Board for Research Education (FUN - Forskarutbildningsnämnd) supervises, evaluates, and ensures the quality of research education conducted by the faculty. This board consists of a pro-dean of the faculty, six members who are teachers with PhD degrees, and two PhD students. Among other duties, FUN appoints the opponent and committee members for each PhD defense.

The Department Board for Graduate Education (*FANS* - Forskarutbildningsansvariga) supervises graduate education at the department of Computer and Information Science (IDA). It is composed of the Department Chair, the Director of Graduate Studies, five PhD supervisors (one appointed by each of the five divisions in the department), two PhD student representatives, and the Graduate Studies Administrator. The board meets at least four times a year to deliberate and decide on all issues relevant to PhD education. It approves the general study plans, approves the lists of PhD courses, analyses the results and evaluations of PhD courses, discusses the statistics of graduation and admissions, plans the annual PhD supervisors' workshop and PhD students' workshop, discusses current issues, and establishes processes, procedures, and routines regarding all aspects of PhD education.

The day-to-day research and research education work is carried out by the PhD students and their supervisors in 13 research labs/groups organized into five divisions. Out of these 13 labs/groups, 10 are involved in research education in the subject area of Computer Science.

The overall structure presented above is captured in Figure 1.

1.2 The Individual Study Plan

After admission into the PhD studies program, an Individual Study Plan (ISP) is formulated by each PhD candidate together with his/her supervisor. The ISP is then revised and updated each year, during the autumn semester, when a systematic review of each PhD student's progress is performed. It is worth mentioning that, since 2015, as an obligatory appendix to the ISP, we have included a form on which the progress is registered for each individual degree outcome (between 0% and 100%) as well as the means by which this progress has been achieved. The main goal of this appendix is to remind both student and supervisor about each individual outcome that is being pursued, and to let them reflect on their current status and the means by which they will obtain all of their desired outcomes. The ISPs are signed by the student, the supervisors, and the Department Chair and are uploaded into the *PhD studies portal*. Via this portal, the PhD student, the supervisors, the Department Chair, the Director of Graduate Studies, and the Graduate Studies Administrator have access, at any time, to all information regarding the status of each respective student, including his/her ISP. Initially, students that were admitted to and partially financed by CUGS, the national computer science graduate school, had an additional appendix to their ISP, related to the specific requirements of CUGS. Since 2015, the particular aspects related to CUGS have been merged into the common ISP form.

The ISP is an important vehicle for the student, the supervisor, and the department, for activity planning and for following the progress achieved along all components of research education. As result of the annual survey of all ISPs, performed at the department level, any lack of due

progress, as well as situations in which the ISP is not properly followed, is taken up with the respective student and the PhD supervisors involved.

The *PhD studies portal*, developed at the department, is a communication/information/registration framework for PhD students, supervisors, lecturers of PhD courses, PhD supervisors, coordinators of the PhD education, and administrative staff. Everybody involved in some way with PhD education at the department has an account in the system providing certain specific access rights. Via this gateway course proposals are submitted, the current course offerings are available, course registrations are performed, all information regarding PhD students is accessible (supervisors, ISPs, courses, Ladok excerpts etc.), documents regarding processes and routines are posted, and much more. This unique portal is an important instrument for students, supervisors, and responsible staff, providing access to all information related to graduate studies, thus making it easy to follow up, at any moment, on the current progress of each PhD candidate.

2. Environment, Resources, and Area: Staff

There are 18 researchers with docent degrees active as main supervisors in PhD education in Computer Science. Out of the 18, 15 are Professors and 3 are Associate Professors (universitetslektor). All of these 18 main PhD supervisors *are employed by the university.* We have 30 people acting as secondary supervisors (this does not include those who are main supervisors but also act as secondary supervisors for some students), out of which 13 are employed by the university and 17 are external. Every PhD student has at least one secondary supervisor, in addition to the main one. 13 PhD students have two secondary supervisors and three have three. The average number of PhD students per main supervisor is 2.4, with a maximum of 5 students per main supervisor.

What do the above numbers say? We have a large body of supervisors, covering the whole research area. This provides conditions for efficient supervision of each PhD student. The distribution of PhD students per supervisor is well balanced and there are no cases of an excessive number of students per main supervisor. The large body of supervisors also provides an adequate level of security to the students, in the sense that, if an unexpected situation demands it, a new supervisor can be assigned. While such a situation has only happened two times in the last five years, the conditions are given to handle the cases smoothly. During their introduction day, all new PhD students are informed about the possibility of changing their supervisor if needed. They are also informed that, in the case of any problems regarding their research education which might require help from outside their research group, including possible difficulties in cooperation with their supervisors, they should contact the Director of Graduate Studies for advice and action.

All main PhD supervisors are employed by the university, have their work place on campus and are, in principle, available to the PhD students whenever needed. The secondary supervisors are recruited from a broader group. In addition to researchers from the department, secondary supervisors are recruited from other departments inside the university, from other universities (in Sweden and other countries) with which we closely cooperate, and from industry (in Sweden and other countries). This allows us to provide the expertise needed for competent supervision in projects that extend into areas beyond the core competence available in the department.

The basic pedagogical preparation for PhD coordination is obtained via the advanced pedagogy course for coordination in research education (*Research supervision – Advanced Course in Higher Education Pedagogy)* provided by the university, which is obligatory in order to become a main PhD supervisor (and to obtain the docent title). In order to prepare them for a future career as main PhD supervisors, young researchers starting their academic careers are coopted as secondary supervisors in supervision teams, together with experienced main PhD supervisors.

Each year the department organizes a *PhD supervisors' workshop* which gathers all main and secondary supervisors involved in research education at the department. The day includes, among others, invited talks that address issues like research leadership, introduction of young researchers to life as researchers and research coordinators, and industry cooperation. Supervisors are also updated on new regulations and practices concerning research education. All discussions are oriented around the overall goal of maintaining and improving the high quality of research education.

The department is continuously working to detect potential problems and to improve the quality of graduate education and PhD supervision. For example: During autumn 2015 and spring 2016, the Department Chair, the Director of Graduate Studies, and the Graduate Studies Administrator had 12 separate meetings with small groups of PhD students and supervisors, covering every PhD student and PhD supervisor. These meetings were explicitly and solely devoted to discussing all issues regarding PhD education in order to detect weaknesses and strengths, as they appear from the perspective of each individual student and supervisor, and to identify best practices that should be further encouraged and publicized. The conclusions from these meetings have been discussed both in the PhD supervisors' and the PhD students' workshops, and an action plan has been elaborated that is concretely anchored in the problems as they are perceived at a grassroots level. The process described above is not a one-time exercise, rather it is repeated every other year, after *the PhD student surveys* (conducted by the university) are evaluated. It is part of our general routine, aimed at continuously and quickly detecting shortcomings and continuously improving the qualification of PhD coordinators and increasing the quality of PhD education. ***We are not necessarily going to repeat this when discussing each of the individual dimensions of PhD education, but this process applies to all aspects of our research education, as discussed in the following sections. Together with the systematic follow up on the ISPs, this is our basic, systematic, and continuous approach to following up on the results of our research education and take the appropriate measures to maintain and improve quality.***

The department is continuously dedicated to maintaining a high competence level in research, covering all topics within the area of Computer Science. This includes both new recruitment in the case of retiring staff and, very importantly, recruiting researchers in new emerging areas. This is happening continuously and implicitly serves to maintain a high-quality body of PhD supervisors. Our most recent recruitments, for example, are a Professor in Robotics, an Associate Professors in Wireless Sensor Network Security, and another Associate Professor in Web Information Systems.

3. Environment, Resources, and Area: Research Education Programme Environment

3.1 Recruitment and composition of the PhD students group.

Our recruitment procedure is aimed at getting the most qualified and talented PhD students from all over the world into our PhD education, and is guided by the equal opportunity principles that underlie everything that happens at the university.

The actual process is, of course, influenced by the financing policy of PhD studies, which means that most of our PhD students are financed by external research grants. Consequently, individual positions become open and are announced in connection with the availability of such grants. This is different in the case of students partially financed by CUGS, the national computer science graduate school. CUGS periodically announces PhD student positions in bunches of around 6 positions at a time. All recruitment is performed according to the following rules:

- The positions are publicly announced, posted on the web pages of the university and of the department. Announcements are distributed through various channels by the involved research groups. In the case that several positions are announced (e.g. CUGS), the announcements are sometimes also published in printed media.
- The applications are evaluated by the board of the division triggering the announcement; in the case of CUGS positions, the evaluation is done by the CUGS board. Short-listed candidates are interviewed (via teleconference, if necessary).
- The application packages of candidates proposed for acceptance are forwarded to the Department Chair and the Director of Graduate Studies for approval. At this stage, conformance to formal rules regarding qualification, as well as the availability of the required financing are checked.
- In the case of students that are coming with scholarships from abroad, we strongly and without exception impose the requirement that the scholarship has to be augmented by the hosting research group up to a level such that the monthly income of the student is at least at the level set by the Swedish Institute (currently 15000 SEK). We do not accept students whose scholarship contract with their financing authority implies that the received financial support has to be returned if the studies are not completed successfully.

At the end of 2016 we had 43 PhD students admitted to the subject area of Computer Science. More than half of them (23 out of 43) come from outside of Sweden, which provides a very fertile and exciting multicultural environment. All aspects of PhD education are conducted in English. Since mastering the language is a de facto requirement for being accepted, the international students do not face difficulties from this point of view in their education.

Regarding gender distribution, 19% of our PhD students are female. While this is far from the desired gender balance, it is worth noting that this percentage of female students is above the corresponding percentage at the undergraduate level in the Computer Science related areas (which, unfortunately, is below 10%). As will also be mentioned later, we are conscious of this problem

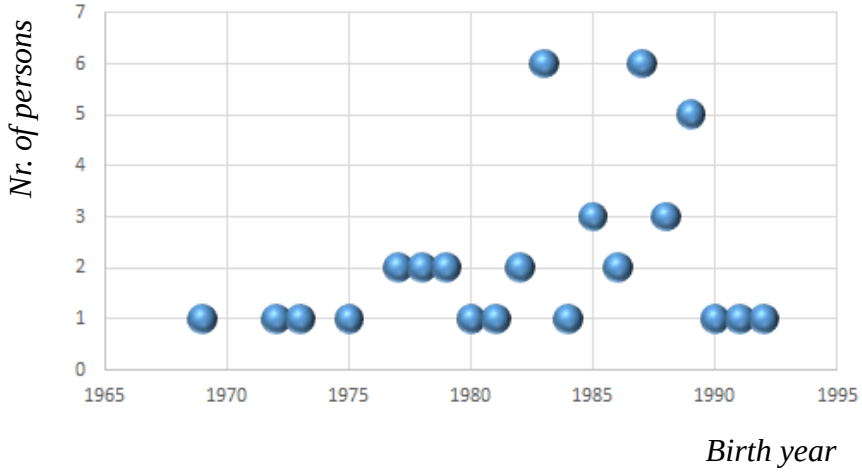

Figure 2. Age distribution of PhD students in Computer Science

and are actively working towards improving the gender balance.

The distribution by age of the PhD students in Computer Science is illustrated in Figure 2.

75% percent of the PhD students in Computer Science are employed by and located in the department. 7 students are "industrial PhD students", who are primarily located at the respective company or organization. For each industrial PhD student, a contract is signed with their employer before admission, which stipulates the company/organization's obligations in providing the necessary conditions for efficiently pursuing the PhD education. By signing this contract, the company/organization guarantees that financing will be provided over the duration of the studies, that the required conditions will be made available to pursue the research, and that the student will be guaranteed to spend a certain amount of time at the department. This arrangement has been quite successful. We have had few problems with industrial PhDs and, on the contrary, they represent a valuable bridge for maintaining contact with industry and transferring research results to actual companies.

We currently have one student whose PhD student employment is with Jönköping university. Three of our current PhD students have moved to jobs in industry but are continuing their PhD studies. They, in continuation, update their ISPs as required, have periodic contact with their supervisors, and their progress is regularly monitored.

We currently do not have any PhD students who are financed by scholarship.

3.2 Composition of the PhD supervisors group

The total number of PhD supervisors in Computer Science is 48 (male: 42, female 6), out of which 18 (male: 16, female 2) are main supervisors. All the main supervisors are permanently employed by the university and are located on the campus. Out of the 30 secondary supervisors,

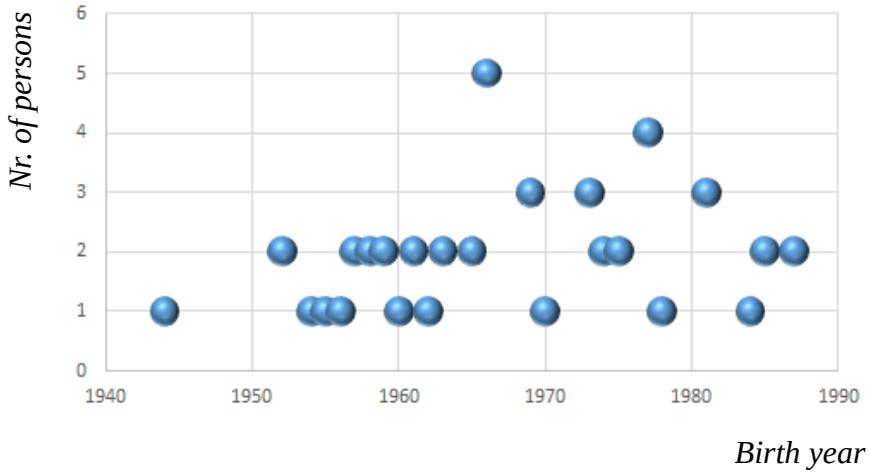

Figure 3. Age distribution of PhD supervisors in Computer Science

13 are employed by and located at the university. The rest are employed by universities, companies and other organizations in and outside of Sweden. Their participation is an important asset, bringing in needed knowledge in related areas as well as valuable industrial experience. Interaction with these supervisors, even if they are located far away, is solved efficiently over remote connection.

Composition by age of the PhD supervisors body is illustrated in Figure 3. The diagram shows that supervisors approaching retirement age are balanced by young incoming supervisors and that we have a peak around the age group of 50. As mentioned earlier, our recruiting policy is targeted at compensating for future vacancies as well as attracting talent in new emerging topics.

3.3 Research Environment and Cooperation

Research education in Computer Science is performed as an intrinsic part of a highly competitive international level research environment at the Department of Computer and Information Science (IDA). All main PhD supervisors and most of the secondary supervisors are well established and internationally recognized researchers, strongly involved in their communities and related networks (e.g. HiPEAC, ArtistDesign, Nordic Multicore Initiative, Object Management Group), actively publishing, editing journals, and organizing workshops and conferences.

A very large part of research financing in the department comes from external grants from European and national sources (e.g. VR, SSF, Vinnova, EU FP7, EU H2020) that also involve important industry participation (e.g. Sectra, Ericsson, Enea, Opera, Spotify, FOI, SICS, ABB, Saab, VTI, SCANIA, Volvo, Autoliv, Google, Siemens, Bosch).

This environment, as outlined above, offers an excellent context in which all PhD students are exposed to contacts with the international and national research community as well as industry. These contacts are materialized in visits to partner universities, project meetings at national and international levels, and participation in workshops and conferences.

Research seminars, organized periodically at division level, regularly host international lecturers, which provides another opportunity for our PhD students to maintain contact with the international community. A large number of our PhD students also participate in courses given at international summer schools. Many students are taking PhD courses at other universities in and outside of Sweden. PhD courses given at the department are often organized with the cooperation of international lecturers who are among the most prominent in their respective research areas.

An important component in defining our graduate education environment is CUGS, the national computer science graduate school. Besides partially financing PhD student positions, CUGS also finances a number of PhD courses, as well as international postdoc positions at the department. This also contributes to a dynamic, international environment with a continuous infusion of fresh ideas.

The department is involved in three major national research initiatives: (1) *ELLIIT*, a strategic research environment funded by the Swedish government in 2010, as part of its initiative to support research in information technology and mobile communications, (2) the *Wallenberg Autonomous Systems and Software Program* (WASP), Sweden's largest ever individual research program, and (3) *Security Link*, one of two strategic research centers in the area of Security and Crisis Management, granted by the Swedish government. All three programs involve several universities and major Swedish companies and institutions. They strongly contribute to our graduate studies environment with PhD courses, workshops, common projects that bring together students from the participating universities, and regular interaction with the participating industrial partners.

An important component of the research environment is the technical infrastructure, consisting of the advanced equipment available in the research laboratories. We mention, for example, the two dedicated robotics labs, the unmanned autonomous aircraft lab, the functional magnetic resonance imaging support, the hospital emergency room, and the multicore computing lab (donated by Ericsson).

Our PhD students' workshop is organized each year in cooperation with a local company and is located at the premises of that company (2015 it was Ericsson, 2016 Sectra). This provides another excellent opportunity for PhD students to understand the problems and needs of industry and society, and to prepare for their future professional careers.

3.4 Quality of Dissertations

The final dissertation is, without doubt, the defining result which materializes the efforts of years of research education. Thus, the dissertations are an important indicator of the overall quality of the research education, and maintaining their high standard should be a primary goal. Throughout the whole research education process, starting with the first introduction meeting with the director of graduate studies, through the regular meetings with the supervisors, and the periodic updates of the individual study plan, the convergence towards the dissertation and its quality is kept in view.

Table 1. PhD students graduated with a PhD degree between 2012 and 2016

PhD student	Number of peer-reviewed publications			Nett time to graduation (years)	First Employment
	Conference	Journal	Book chapter		
Mohammad Saifullah	5	1	1	4,56	ASA University, Bangladesh
Usman Dastgeer	15	4	1	3,41	Ericsson, Linköping
Magnus Ingmarsson	6			5,30	COGTECH, Linköping
Dag Sonntag	5	3	1	3,40	ASML, Qbiz, The Netherlands
Magnus Jandinger	13	2	1	5,58	Acando Consulting AB, Göteborg
Sara Stymne	22	1	1	3,86	Uppsala University
John Wilander	5			4,23	Apple, Cupertino, USA
Rahul Hiran	5			4,97	*Just graduated in December - Papaledig*
Anna Vapen	7	2		7,11	Mindcamp AB, Göteborg
David Byers	10	3	2	4,87	Linköping University
Håkan Warnquist	7	3		4,80	Scania, Södertälje
Kristian Stavåker	11	1		4,99	EQUA Simulation AB, Stockholm
Martin Sjölund	22	3		3,61	Linköping University
Roland Samlaus	4	1		2,89	Robert Bosch GmbH, Stuttgart, Germany
Wladimir Schamai	11	2		4,23	Airbus Group, Hamburg, Germany
Victor Lagerkvist	8	4		2,84	Technische Universität Dresden, Germany
Hannes Uppman	4			4,71	Freelance
Tommy Färnqvist	7	2		4,37	Linköping University
Amir Aminifar	9	1		3,98	École polytechnique fédérale de Lausanne
Bogdan Tanasa	8	1		4,33	Saab, Linköping
Adrian Lifa	7	1		4,97	Autoliv AB, Linköping
Sergiu Rafiliu	3	2		4,97	Ericsson, Linköping
Chandan Roy		2	1	4,85	University of Rajshahi, Bangladesh
Ekhiotz Vergara	10	3	1	4,20	Combitech, Linköping
Maria Vasilevskaya	4	2		4,22	CapGemini, Stockholm
Erik Kuiper	3	2		3,05	Saab, Linköping
Ke Jiang	13	2		5,12	Autoliv AB, Linköping
Nima Aghaee	8	3		4,22	Guideline Geo, Stockholm
Tomas Bengtsson	9	1		3,82	Prevas AB, Västerås

In addition, the following specific actions are taken in order to guarantee the required standard of quality for dissertations:

All PhD dissertations have to be rooted in peer-reviewed publications at international conferences and/or in scientific journals. This is the case, regardless of wether the final dissertation is organized as a collection of papers or as a monograph. In the area of Computer Science, publications at top conferences have a status similar to those in a good journal. All of our PhD students publish their work in conferences and/or journals, being confronted with the international research community. No dissertation will be defended before the research results have passed the scrutiny of peer review with international experts. This is confirmed in Table 1, which shows the number of peer-reviewed publications related to our students' PhD research, for all students that have graduated with a PhD degree in Computer Science between 2012 and 2016.

Before starting the formal process leading to the PhD/Licentiate defense, the thesis has to be defended internally, in a seminar that is conducted inside the respective division. This provides an-

other opportunity for quality checking and possible final improvement.

While not obligatory, some of our PhD candidates also write and defend a Licentiate thesis. We see the Licentiate mainly as a step towards the PhD degree, particularly in situations in which the PhD student and the supervisor feel that such a formal checkpoint is needed for that particular student. As such, it becomes a step in the process leading to a high quality PhD thesis.

Having a strong examination committee and opponent will not solve any quality problems in the actual thesis on defense, but it does help to maintain and continuously improve the high standards of quality, by exposing the work to the highest level of scrutiny and receiving valuable feedback and suggestions. According to our current process, both the opponent and the examination committee members are appointed by the Faculty Board for Research Education. This is done based on a written document from the department, which provides evidence for why the proposed candidates are appropriate, given their qualification and their level of international recognition. The board makes its decision after a discussion with the PhD supervisor, regarding the content and contributions of the thesis, the quality of the related publications, and the qualification of the opponent and examination committee members. Both for committee and opponent, very strict rules are applied in order to avoid any conflict of interest.

Before proceeding with the public announcement of the defense, all examination committee members are required to provide a written statement that, according to their evaluation, the thesis is at a level appropriate to be put forward for public defense.

3.5 Maintaining a High Quality Research Education

Maintaining and improving the quality of the overall research and research education environment is an ongoing objective of the Department Board for Graduate Education (FANS) and is a permanent topic at its meetings. Discussions at both the PhD supervisors' and PhD students' workshops are focused on potential shortcomings and possible improvements regarding all aspects of the working environment. Our PhD student surveys and our periodic meetings with PhD students have shown that the general research and working environment is well appreciated.

At the level of individual students, the ISP is an important vehicle that allows for follow up on, among other things, progress with publications, participation at conferences, involvement in projects, and progress in the dissertation work. As a result of our annual survey of all ISPs, any lack of appropriate progress, as well as any situation in which the ISP is not properly followed, is taken up with the respective student and the PhD supervisors involved.

4. Design, Teaching/Learning and Outcomes: Achievement of Qualitative Targets for "Knowledge and Understanding"

Research education in Computer Science comprises two main components: (1) The research work, which is materialized in publications, project reports, and the final thesis; according to the general study plan, this part stands for 150 ECTS points (60 ECTS for Licentiate); (2) Course

work, equivalent to 90 ECTS points (60 ECTS for Licentiate).

Research work is performed continuously, in a natural progression, from the first day up to the defense of the final dissertation, under the continuous guidance of the main and secondary supervisors. The first version of the ISP has to outline the overall research goal and the formulation of the research problem being approached, as well as the first concrete research objectives. A first period of thorough literature study, together with the first PhD courses, provides the appropriate knowledge (breadth and depth) of the area, needed in order to proceed with the research work. Successive progression in research results, publications and courses, as documented and followed in the ISP, leads towards the PhD dissertation and the fulfillment of the intended qualitative targets.

4.1 PhD courses; broad and deep knowledge

Our PhD course offerings are coordinated at the department level and are shared among the research education subject areas of Computer Science, Statistics and Machine Learning, and Cognitive Science. This means that there is a single common course list offered for all three subject areas, from which the students, together with their supervisors, select courses as appropriate, given their research direction and according to the requirements specified in the general study plan for their research education area. This practice contributes to providing the breadth that is required as one of the study outcomes. Moreover, students can also select from a set of common courses given at the faculty level (such as the compulsory courses *Methodology of Science and Technology* and *Research Ethics*) and can also attend PhD courses given by other departments, such as mathematics and electrical engineering.

The list of PhD courses being offered is produced by the department every year, based on proposals from the teaching and research staff:

1. A call for proposals goes out in September, asking for courses to be given in the coming calendar year.
2. Course proposals, (including course plan, goals, examination, etc.) are submitted, via the *PhD studies portal*, before the last week of November.
3. The department board for graduate education (FANS) studies the course proposals and approves the list that goes out to the PhD students.
4. PhD students register their interest for the courses they plan to take in the coming year.

All approved courses with a minimum of five participants (with possible exceptions in the case of very specialized in-depth courses) receive financing from the department. The fact that the course list for the whole next year is out before December helps the students to adequately plan their research and course work and update their ISP.

Table 2. PhD courses offered 2012 -2016, at department level

Titel	2012	2013	2014	2015	2016
Artificial Intelligence	x				
Advanced Algorithmic Problem Solving		x	x		x
Advanced Bayesian Learning			x		
Advanced Compiler Construction	x		x		x
Advanced Data Models and Databases	x	x	x	x	x
Advanced Machine Learning					x
Advanced Networking				x	
AI Robotics		x			
Artificial Cognitive Systems		x			x
Automated Planning	x	x			
Bayesian Learning	x	x	x	x	x
Challenges of Secure Computation and Communication on Energy-constrained Devices				x	
Cognitive Aspects of Learning and Design of Edcuational Technology	x	x	x		x
Cognitive Neuroscience Methods & Data Analysis	x	x			
Cognitive Systems Engineering: Automation and Safety			x		
Computation II	x	x	x	x	x
Current Topics in Human-Computer Interaction		x			
Data Mining and Statistical Learning	x	x			
Database Systems	x				
Decision Making and Process Tracking	x				
Design Research Methodologies				x	x
Design Research Methods	x				
Design Research Seminar				x	x
Developing Software Games	x	x			
Discrete Structures II					x
Distributed Algorithms for Fault Tolerance	x				
Distributed Systems	x	x	x	x	x
Embedded Security				x	
Embodied Cognition and Interaction					x
Energy-efficient Networking	x				
Energy-Efficient Parallel Computing		x			
Etnografic Methods	x				
Evolutionary Perspectives on Cognition	x	x			
Functional Magnetic Resonance Imaging (fMRI)				x	
Functional Programming				x	x
General-Purpose Computing on GPGPU: Fundamentals and Beyond		x			
Health Informatics	x				
High-Level Parallel Programming Project					x
In-depth Introduction to Seven Programming Languages			x		
Introduction to Applied LISREL			x		x

Introduction to Automatic Verification			x		
Introduction to Game Theory		x			
Introduction to Genetic Programming	x				
Introduction to Information Privacy		x			
Introduction to Machine Learning			x	x	x
Introduction to Performance Validation of Embedded Software			x		
Logic II		x		x	
Logic Programming				x	x
Machine Learning - Based Automated Performance Tuning			x		
Machine Learning - Introduction and Application for Automated Performance Tuning	x				
Model-Based Systems Engineering				x	x
Modeling Strange Networks: Algorithms and Applications				x	
Multicore Computing		x			
Natural User Interface Technology (Kinect and others)		x		x	x
Neural Networks with Applicaitons to Vision and Language					x
Principles of Object-Oriented Modeling and Simulation of Dynamic Systems	x	x		x	
Qualitative Research Methods					x
Real-Time and Embedded Systems	x		x		
Real-Time Networks		x			
Requirements Engineering	x				
Resilience Engineering				x	
Scientific Publications	x	x		x	
Semantic Technologies in Practice	x				
Semantics of Programming Langugages	x			x	x
Service Design and Innovation		x	x		
Service Design Research				x	x
Simulators and Simulator Usage				x	
Software Architectures				x	
Software Engineering	x	x	x	x	
Software Engineering Experimentation	x				
Software Performance Validation and Optimization for Advanced Parallel Architectures				x	
Swedish Crisis Management: Command, Control and Coordination	x			x	
Text Mining		x	x	x	x
Theoretical Perspectives in Cognitive Science	x				
Theory and Application of Probablistic Model Checking				x	
Theory and Applications of Tree Automata and Tree Transducers				x	
Transhumnaist Futures and Computing			x		
World Modeling - Sustainability vs Collapse					x

As can be seen from Table 2, the courses cover a broad area from core computer science to artificial intelligence, networking, embedded systems, machine learning, robotics and cognitive systems. Some of the courses are specialized, going deeply into a certain topic, while others are of a more general character, providing fundamental and broad knowledge.

The course offerings are different from year to year, also adapting to the actual needs of the active group of PhD students. Nevertheless, certain courses, in particular those with a more broad, fundamental character, are guaranteed to run every year, or to repeat with appropriate regularity.

According to the general study plan, it is compulsory for all students to choose both courses that provide a broad knowledge and understanding of the field of Computer Science and adjacent related fields, as well as in-depth courses within their particular research area.

In addition to these regular courses, in coordination with their supervisors, students also do individual study courses, in particular on very specialized subjects connected to their research sub-area. It is also possible for PhD students to get relevant courses from their Master's program to be recognized and the corresponding course points transferred to the PhD program. The transfer is performed as result of a written request signed by the PhD supervisor and approved by the Director of Graduate Studies.

Table 2 only contains courses offered by the department. PhD students also take courses given at the faculty level, as well as courses from other departments and universities.

In conclusion, we would like to point out that our goal is to provide each PhD student with the opportunity to select, together with the supervisors, a set of courses that best fits his/her particular background, previous studies, research area, and scientific interests.

4.2 Scientific methodology

The actual research work, systematically performed under the supervision of at least two supervisors, is the most important way in which the student acquires an understanding of the scientific research methodology that is relevant to his/her research area.

From the very beginning, PhD students are made aware of the importance to conduct their research according to appropriate and clean methodological principles. This is also explicitly followed up in their ISP.

A systematic understanding of methodologies and their various characteristics within scientific/ technological research and development is provided by the course *Methodology of Science and Technology* (4 ECTS). This course, given at the faculty level, is obligatory for all PhD students, according to the general study plan.

4.3 Achieving the qualitative targets. Concluding the studies in due time

Together with the research work, our PhD course offerings guarantee that, in addition to deep knowledge in the research area, the students also acquire broad understanding in the overall field of Computer Science. This is also the case with regard to understanding research methodologies, both in the general sense as well as in the specific case of Computer Science. As the students proceed towards attainment of a degree, their progress is continuously monitored via the ISP, which *explicitly* and *quantitatively* indicates the current status of the student, both overall and towards each particular target. The actual status is periodically discussed in detail with each student.

Due to the very nature of research education, and in particular its research component, it is difficult to guarantee that graduation will always be possible after the net four years. Nevertheless, we try to provide an environment that gets us as close as possible to this goal. We aim to minimize possible delays by taking actions like the following:

1. Course offerings are available for one whole year in advance, which allows for careful planning; basic courses are offered every year or with known periodicity.
2. We are continuously working - through our PhD student surveys, periodic meetings with student and supervisor groups, and the PhD supervisors' workshops - towards making sure that all students receive adequate supervision and get the opportunity to meet with their supervisors with sufficient frequency, and always when needed.
3. We work to ensure that students get rapid feedback to their draft manuscripts (papers and dissertation). A nice answer we got from some students when we were investigating this particular aspect: "It seems that our supervisors never sleep!".
4. The ISP is an important vehicle for following the progress achieved by each PhD student. After conducting the annual survey of all ISPs, performed at the department level, any lack of appropriate progress, as well as any situation in which the ISP is not properly followed, is taken up with the respective student and the PhD supervisors involved.

The net time to graduation is shown in Table 1 for all students who graduated between 2012 and 2016.

5. Design, Teaching/Learning and Outcomes: Achievement of Qualitative Targets for "Competence and Skills"

5.1 Plan and perform research in given time frame

Time is our most important resource in research (and not only). PhD students quickly realize this, but they need training in order to understand how to handle it. Managing their time and planning their work is one important skill the students learn as part of their research education. This issue is always present during the supervisory meetings.

The most common context in which students are facing hard deadlines, in the research setting, is publication. It is an education that all PhD students are going through. Together with their super-

visors they plan their research such that results are available and the paper is written and submitted on deadline.

Working on research projects with deliverables that must be produced on deadline is common for the vast majority of our students. Being part of such a project team is the best school for learning how to plan your time and set priorities for your work.

A moment in which work planning is central is the periodic updating of the ISP. This is an important opportunity for learning about middle and long term planning. It also provides the student with the opportunity to reflect on the previous planning period, on what has been fulfilled in time, and where and why the plan has failed.

5.2 Oral and written presentation of results in an international context

We all understand the importance of being able to communicate research results to the scientific community as well as to a broader audience, both inside and outside of academia. High quality oral and written presentation skills are obligatory today for every researcher. Achieving such skills is an explicit goal of our research education.

We do not make any distinction between the national and international arenas with regard to scientific publication and interaction with the scientific community. The main vehicle for such an interaction is by scientific publication and participation at conferences. All of our PhD students, without exception, are publishing their results in international conferences/journals, and are orally presenting their work at conferences and workshops. In this way all students acquire competence in both oral and written communication with the scientific community. The acquired skills are ultimately demonstrated by writing the PhD dissertation and defending it in front of the committee.

Due to their involvement in various projects, most of our students are also writing technical reports and other deliverables, and are also involved in the formulation of project proposals. Many PhD courses require, as part of the examination, written reports supported by an oral presentation.

Scientific communication is also learned by giving periodic presentations within the seminar program of each division and research group. Last, but not least, the department regularly offers the PhD course *Scientific Publication* (5 ECTS), which is very popular among PhD students and is taken by the vast majority of them.

5.3 Contribution to social development and teaching

Most of our PhD students are financed by and working on research projects that include participation from industry and other organizations. This allows them both to understand the priorities and needs of industry and society and to learn how to interact with their representatives. They also

learn how to transfer research results and technologies into practical use by external partners.

Another channel for interaction with industry and society is by advising Master's projects that are conducted outside the university. Most of our undergraduate students are working on their Master's thesis at various companies and organizations, and have an examinator and a supervisor from the university. This supervisor is typically a PhD student who is keeping in contact with the student and his/her supervisor from the partner's side. This provides an interesting experience in both interacting with industry and advising students in their thesis work.

All employed PhD students are involved in teaching up to the level of 20%. In order to prepare for this activity, they have to take the course *Learning and Knowledge (LoK) - Basic course in higher education pedagogy.*

6. Design, Teaching/Learning and Outcomes: Achievement of Qualitative Targets for "Judgement and Approach"

PhD research is, to a large extent, individual work. Of course, it is performed under supervision. Sometimes, parts of the work are performed in a team, possibly together with other PhD students. In this case, however, responsibilities are clearly defined and contributions well delimited. The amount and nature of supervision also changes, progressively being adapted to the increasing independence of the PhD student in his/her research work. The topic of how to support and encourage this progression towards independent work is addressed in our PhD supervisors' workshops, and also in the course *Research supervision – Advanced Course in Higher Education Pedagogy*, which is obligatory for each PhD supervisor.

The development of each PhD candidate towards becoming a fully independent researcher is explicitly documented in the ISPs.

Regarding the understanding of ethical aspects of research, we believe that a very important component is the supervisor's personal example, conveyed throughout the whole PhD education process. PhD supervisors are aware of this aspect of research education (also discussed in the above mentioned obligatory research supervision course), and it is also included in the ISP. It is mandatory for all PhD students to take the course *Research Ethics* (2 ECTS), which addresses issues such as responsibility in research, ethical vetting, secrecy and confidentiality, and scientific misconduct.

Since publication is obligatory for all PhD students, they become familiar, under the guidance of their supervisors, with the ethical aspects involved in the publication process: plagiarism, proper citation, blind reviewing, copyright issues, and conflicts of interest. Moreover, many students' supervisors involve them in the process of reviewing scientific papers, which further facilitates their understanding of these ethical aspects.

7. Working Life Perspective

As mentioned earlier, most of the financing for PhD students comes from external research grants, many of which are based on projects involving industry partners (see also Section 3.3 - Research Environment and Cooperation).

The department is involved, as mentioned in Section 3.3, in three major national research initiatives: (1) *ELLIIT*, a strategic research environment funded by the Swedish government in 2010, as part of its initiative to support research in information technology and mobile communications, (2) the *Wallenberg Autonomous Systems and Software Program* (WASP), Sweden's largest ever individual research program, and (3) *Security Link*, one of two strategic research centers in the area of Security and Crisis Management, granted by the Swedish government. All three programs involve strong participation from industry and other organizations.

Our PhD students' workshop is organized each year in cooperation with a local company and is located at the premises of that company (2015 it was Ericsson, 2016 Sectra). The workshops feature both presentations from industry and from our alumni.

PhD students, supervisors, as well as the staff responsible for PhD education (e.g. the Director of Graduate Studies) are exposed to continuous interaction with industry and society beyond the limits of the university. The consequences are twofold: (1) Research work, as part of PhD education, is adapted to the needs of industry and society; (2) PhD students and supervisors have direct experience of interacting with industry and being ready to understand research from this particular perspective.

Another factor that provides the students with perspectives on working life is their role in advising Master's projects that are performed at companies or other organizations. As mentioned in Section 5.3, most of our undergraduate students are working on their Master's thesis outside the university and have an examinator and a supervisor from the university. This supervisor is typically a PhD student who is keeping in contact with the student and his/her supervisor from the company side. This provides an interesting experience and an understanding of the requirements of working life.

We should also not forget that a significant number of secondary supervisors are employed in industry, which brings the work-life perspective directly into the team.

Another aspect of preparation for working life is determined by the fact that a large proportion of our PhD students come from abroad. Language barriers, with regard to their research education, do not exist, since all PhD education is conducted in English. Nevertheless, if we consider their future integration into working life, there is a potential language problem since a vast majority of these students stay and work in Sweden after their graduation. In an effort to address this, the department actively encourages international PhD students to learn Swedish by, for example, financing language courses.

We stay in contact with our alumni and make use of their experience as often as possible. For our annual PhD students' workshop we have regularly invited some of our alumni who are working in industry or academia, to give talks about their experience and how they look back at their time as PhD students. Several of our alumni, after leaving Linköping University, have continued to be active as secondary PhD supervisors.

PhD supervisors and students conduct career planning discussions, well in advance of graduation. These discussions are obligatory, and are also explicitly recorded in the ISP.

The majority of our PhD graduates move to Research&Development positions in industry. While this is typical for the Computer Science area, we also have a significant number of graduates who are pursuing careers in academia. While, like all other PhD students, they also need to be exposed to an interaction with industry, their career coaching has to be different. So, for example, in one of our PhD students' workshops we have taken up the issue of how and why to find a good postdoc position, and we have also invited postdocs to present from their own experience.

In Table 1 we have also indicated the first employers of our PhD students who graduated in the interval 2012 - 2016.

All PhD students employed by the university are involved in teaching for, on average, 20% of their time. This is yet another opportunity to prepare for their professional careers.

Maintaining relevance from an industrial and social perspective is a central goal of our research and research education work. In fact, from this perspective, there is an extremely strong connection between research and research education. Interacting with industry is a part of everyday reality for both our PhD supervisors and PhD students, and the feedback is directly integrated into research and research education, in order to keep up their practical relevance.

8. Doctoral Student Perspective

We are aware of the fact that the overall quality of our research education is highly dependent on the working environment provided to our students and on our ability to actively involve the PhD candidates in the continuous improvement of all aspects of this education.

8.1 PhD Student representation and participation

PhD student representatives sit on the boards at the University, Faculty, Department, and Division levels. Maybe more important in this context are the bodies explicitly dealing with PhD education issues (see also Figure 1): The Faculty Board for Research Education (FUN), and the Department Board for Graduate Education (FANS). There are two PhD student representatives on each of these boards.

In order to continuously and actively participate in shaping all aspects of PhD studies and maintain strong grassroots connections, PhD students in the Department of Computer and Information Science (IDA) have established a PhD students' organization with representatives sitting on the PhD Students Council of IDA. This council nominates the two PhD student representatives who sit on the Department Board for Graduate Education (FANS). The connection via the student representatives in FANS to the PhD students council and the large body of PhD students allows us to consider the students' input in all decisions that are made by FANS. This is one of our vehicles towards mobilizing the students and making them part of the work aiming at continuously improving research education.

Another important channel through which we receive feedback from all PhD students is via the PhD students survey, run by the university every other year. It covers all aspects of the PhD students' activity, from recruitment to supervision, courses, and environment. The results are reported back at university, faculty, and department levels. As also mentioned in Section 2, after every round of this survey we run an extensive and thorough process in which, together with students and supervisors, we evaluate the results, identify strengths and weaknesses, and develop action plans. For example, during autumn 2015 and spring 2016, the Department Chair, the Director of Graduate Studies, and the Graduate Studies Administrator had 12 separate meetings with small groups of PhD students and supervisors, covering every PhD student and PhD supervisor. These meetings were explicitly and solely devoted to discussing all issues regarding PhD education in order to detect weaknesses and strengths, as they appear from the perspective of each individual student and supervisor, and to identify best practices that should be further encouraged. The conclusions have been discussed both in the PhD supervisors' and the PhD students' workshops and an action plan has been developed that is concretely anchored in the problems as perceived at the grassroots level.

8.2 Working environment: physical and psycho-social wellbeing

Concerning the physical work environment, we can confidently state that our PhD students are provided with excellent conditions. All students are provided with individual offices (identical to those of their supervisors) with all the necessary equipment in place. Additional space for informal activities and social interaction in smaller or larger groups is available. Easy access to physical and sport activities on campus is also provided.

All PhD students have access to occupational health services, physiotherapy, and rehabilitation, provided by a specialized partner company.

One aspect that our investigations have revealed is that our PhD students are experiencing stress which, of course, can affect their psychological wellbeing. They all realize that some of this stress is an inherent side effect of any creative scientific work, and it is also perceived as positive and mobilizing. Nevertheless, there is a component of this stress that is both negative and avoidable. It emerged that much of this stress is generated by the difficulty of properly combining teaching

with the research work based on appropriate middle and long term planning. To address this, we asked each study director (who are in charge of organizing undergraduate teaching and assigning teaching responsibilities) to hold, before every planning period, individual meetings with the PhD students and discuss their potential teaching assignments with them, with emphasis on how they could be organized and planned in the best possible way. This provides the students with an opportunity to better control and plan their middle and long term workload and correspondingly set their priorities.

In order to help the students handle professional challenges and related stress, every year the department organizes the *Development Program for PhD students - Handling the challenges of being a PhD student*, with help from a specialized company in personal/team/leadership coaching. The program consists of three modules (of three sessions each): (1) The role of a PhD student - my personal leadership, (2) A competitive, high performance environment, and (3) From PhD student to PhD. The content of the program has been established based on interviews with students and is continuously updated. The feedback from participants has been very positive.

Every year the department organizes a *feel-good day*, in which all personnel, including PhD students and supervisors, spend a whole day together, outside the campus. This further helps integration among PhD students from different groups, as well as between PhD students and supervisors.

A potentially difficult period in every student's life has to do with adapting to the new environment when starting research education. During this initial period, in addition to the standard introduction for every new employee, we support new students in several ways and according to their individual need:

1. Introduction day, organized by the department for new PhD students.
2. Practical support provided by the administration and technical staff, according to a detailed checklist.
3. A dedicated web page with advice, FAQs, and useful links for new PhD students.
4. Mentor program: Each new PhD student is assigned a senior student as a mentor. The program extends over one year, during which mentor and mentee meet periodically (at least once a month) and always when needed.

As previously mentioned, we are continuously preoccupied with receiving feedback from PhD students, regarding their studies and wellbeing, and with improving our education and environment based on this feedback. First, we are continuously receiving opinions from PhD students via their representatives at the various levels. Every other year, a broad survey involving all PhD students is conducted. We have periodic meetings in which the department leadership meets with all students and supervisors, in small groups, to discuss issues related to PhD education. The outcomes of these meetings are then analyzed and discussed by the Department Board for Graduate Education and the Board of the Department, after which the conclusions and the related action plan are communicated back to all students and supervisors. They are also discussed in both the PhD students', and the PhD supervisors', workshops.

9. Gender Equality Perspective

The Gender Equality strategy followed by the department, in the context of research education, is part of a broader equal opportunity strategy which has its roots in the strategy and action plan developed at the university and department levels. The overall goal is to prevent and combat discrimination, harassment, and sexual harassment in all aspects of research education from recruitment to thesis defense. This is an integral part of our work towards a high quality research education and it is implemented in cooperation with the equal opportunities representative at the department level.

Equal opportunity, in this context, concerns work and study conditions, salaries, influence, career prospects, and the opportunities to combine a professional career with the responsibilities of home and family. We have worked and are working towards making sure that there is an awareness of the gender equality issue throughout all components of research education. This is achieved by addressing gender awareness in the obligatory course *Research supervision – Advanced Course in Higher Education Pedagogy*, which is obligatory for each PhD supervisor, in the annual PhD supervisors' workshop, and our periodic meetings with students and supervisors. Information about equal opportunities is also included in the welcome package for new students and employees.

Gender equality issues are also addressed in the course *Learning and Knowledge (LoK) - Basic course in higher education pedagogy*, which is compulsory for all PhD students involved in teaching.

From the formal point of view, all our regulations and processes are, of course, designed to guarantee complete gender equality. Nevertheless, work is continuously being done in order to convert this into actual equality, providing equal opportunities in practice.

Regarding the gender distribution, 19% of the PhD students are female. While this is far from the desired gender balance, it is noteworthy that this percentage of female PhD students is much larger then the corresponding percentage at the undergraduate level in the Computer Science related areas (which, unfortunately, is below 10%). Out of the total number of 48 PhD supervisors in Computer Science, 6 are female.

As we are aware of the underrepresentation of women, both as PhD students and supervisors, we are continuously working to improve our gender balance record. The basic idea is to not lose potential female candidates for PhD studies, to support career planning of our female research and teaching staff, and to detect any potential gender discrimination and lack of fairness in the research education process.

This work starts with the recruitment of PhD students, where we constantly encourage promising female candidates from our undergraduate and Master's programs to not miss applying for open PhD student positions. A special scholarship has been established by the department, which is awarded every year to a female computer science/engineering student with a distinguishing record. The scholarship finances a study trip to the USA, with visits to universities and compa-

nies, and participation at the *Grace Hopper Celebration of Women in Computing* conference. This should encourage an appetite for future research studies.

In order to better balance the composition of our research and teaching staff, the department has a program to provide counsel and guidance to our female PhD graduates aimed at encouraging them to embrace an academic career. As part of the same program, the progress of our young female researchers is carefully followed, and they are particularly supported in their efforts towards promotion to the docent degree, which entitles one to act as a main supervisor.

It is worth mentioning that, according to our PhD students survey, none of the students in our department has experienced any gender related discrimination related to their activity in the university.