Student Enrollment and Image of the Informatics Discipline

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... decades of stunningly rapid advances in processing speed, storage and networking, along with the development of increasingly clever software, have brought computing into science, business and culture in ways that were barely imagined years ago. The quantitative changes delivered through smart engineering opened the door to qualitative changes. Computing changes what can be seen, simulated and done. (Stephen Lohr, 2006)

Summary

Despite the fact that Computing/Informatics impacts on everything around us and is an unprecedented source of new qualities in science, in business and in our daily lives, the number of beginning students in informatics has been steadily dropping over the past years in many countries. The 'enrollment crisis' is cited as one of the prime reasons why science is not profiting from the achievements of computer science in depth, why industry is not able to recruit even a fraction of the highly skilled IT specialists and software engineers that it needs, and why the information society is deprived of the many beautiful intelligent systems that modern computer science could lead to. Universities in Europe are turning out excellent graduates in Informatics but are doing so in numbers that seem way too small.

Why is student enrollment a problem in Informatics/Computing, at least in many of the (Western) European countries? Why is enrollment by female students lagging behind? What are the reasons of it, and what can be done about it? Are there best practices in certain countries from which we can all learn and benefit? Do potential students have the right image of Informatics as a field of study, as a science, as a profession? How should the field be positioned so it is "clearly" as attractive and challenging as many other disciplines and perhaps even more so?

The Working Group on 'Student Enrollment and Image of the Discipline' was created to collect insights on these issues and to come up with a document that advises the Informatics Europe membership on the state of the problem and on possible measures that could be taken to resolve it. The present document is a very preliminary report on the results of the Working Group.

Working group

This report is based on the contributions of the following members of the Working Group. The text developed initially through a wiki site provided by Informatics Europe.

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1 Introduction

(Jan van Leeuwen/Letizia Tanca)

> *What motivates anyone to study computing? A natural curiosity about the underlying concepts? The field's potential usefulness to other areas? Programming? The ability to advise less technically literate colleagues? Building websites or designing systems, including video games?*
> V.L. Almstrum (2003)

Despite the fact that Computing/Informatics impacts on everything around us and is an unprecedented source of new qualities in science, in business and in our daily lives, the number of beginning students in informatics has been steadily dropping over the past years in many countries. The 'enrollment crisis' is cited as one of the prime reasons why science is not profiting from the achievements of computer science in depth, why industry is not able to recruit even a fraction of the highly skilled IT specialists and software engineers that it needs, and why the information society is deprived of the many beautiful intelligent systems that modern computer science could lead to. Universities in Europe are turning out excellent graduates in Informatics but are doing so in numbers that seem way too small. In the US it is not better.

> *Recent declines are particularly pronounced in computer science. The percentage of college freshmen planning to major in computer science dropped by 70% between 2000 and 2005. In an economy in which computing has become central to innovation in nearly every sector, this decline poses a serious threat to American competitiveness. Indeed, it would not be an exaggeration to say that every significant technological innovation of the 21st century will require new software to make it happen.*
> Bill Gates (2007)

Why is student enrollment a problem in Informatics/Computing, at least in many of the (Western) European countries? Why is enrollment by female students lagging behind? What are the reasons of it, and what can be done about it? Are there best practices in certain countries from which we can all learn and benefit? Do potential students have the right image of Informatics as a field of study, as a science, as a profession? How should the field be positioned so it is 'clearly' as attractive and challenging as many other disciplines and perhaps even more so? Should we worry at at all, given that the numbers of students are still better than in some other science disciplines? Isn't it a cyclic thing anyway?

> *... there are today more computer science students [in the UK] than in all of the more traditional sciences - physics, chemistry and biology - put together. Even so, few would argue that basic physical science is dying, or losing out to industrial research, just because it is sometimes hard to recruit undergraduates from our school system.*
> Y. Wilks (2007)

In this report we analyse some aspects of these issues and develop suggestions for the Informatics Europe membership on the state of the problem and on possible measures that could be taken to resolve it. We hope the insights contribute as an effective source of inspiration for improving the overall view and attractiveness of the discipline of Informatics.

> *... We're trying to strengthen America's competitiveness in this global economy, and we know that workers have to know and understand math and science, and once kids drop out of math and science they never seem to get back into it. So, how do we do that? Do we have to fire them up with fear or just desire of knowledge? How do we get kids interested in the science and math fields?*
> Senator M.B. Enzi, in: U.S. Senate (2007)

1.1 In Progress

The enrollment problem has hit all sciences since the mid nineties. It is a notorious and complex problem that has led to many discussions and attempts to understand it as a phenomenon. At present the enrollment problem for Informatics in Europe is certainly not a uniform problem: it isn't a problem everywhere, in some cases it is not a problem anymore, or ... not yet. Many possible causes of the problem have been proposed in the past, and likewise it is generally felt that there is *no silver bullet* for remedying the problem. Only a combination of efforts will get us somewhere, and some of the needed measures may require a drastic change of vision in the entire definition of our curricula. Indeed, we may need a whole new perception of Informatics/Computing as a discipline in order to attract young people and to unleash their endless energy and creativity for the benefit of the field.

In this preliminary report we explore a broad variety of issues that have all been brought to bear on the enrollment and that are somehow repeated over and over when the enrollment problem is being discussed. Only by diagnosing all aspects of the problem can we expect to find the ingredients for an ultimate solution. Our aim is to give an overview of the many arguments and directions in which the enrollment problem is approached 'under one roof'. The possible solutions certainly need further study and thus we see this document as reporting on 'work in progress'. We hope that the report will stimulate discussions and motivate the members of Informatics Europe already to further and new initiatives in tackling the enrollment problem in our field.

> *As the years went by [...] fewer and fewer young [people] were captivated by national challenges like the race to the moon or felt the allure of math, science, and engineering. In universities [...], graduate enrollment in science and engineering programs, having grown for decades, peaked in 1993, and despite some recent progress, it remains today below the level of a decade ago. So the science and engineering generations got smaller and smaller relative to our needs. [...] For the first time in more than a century, [we] could well find [ourselves] falling behind other countries in the capacity for scientific discovery, innovation and economic development.*
> From: Th.L. Friedman, The World is Flat, 2005/2006, p. 328.

2 Analysis of the Problem

(Jan van Leeuwen/Letizia Tanca)

Information technology is invading every aspect of science and society. While the demand for expert researchers and designers in science and industry is greater than ever, the interest among prospective students for academic studies in Informatics or Computing is not developing at an equal pace. Many universities in (Western) European countries have rather seen sharp drops in the enrollment figures for bachelor studies in Informatics in recent years and the interest for MSc or PhD studies in the field is not compensating for it. The phenomenon has occurred in other sciences as well. What could be the reason of it? We list some common views and prejudices about Informatics to see what conclusions we can draw.

2.1 Views and Prejudices

We list a number of views (and prejudices) that are commonly cited in analyses of the enrollment problem for (bachelor studies in) Informatics.

> ⋆ *Despite the many job opportunities in ICT and excellent career perspectives in industry, enrollment in Informatics is not surging.*

Future possibilities of jobs do not influence students much when they choose the university studies that interest them. There is a positive correlation between the trends in ICT and the growth of the economy and in this way with the choice of academic studies, but the effect is much weaker than one would like (and expect).

> ⋆ *Students are attracted to Informatics because they are attracted to the technology and a later job in ICT, not because they like science.*

This view (or is it a prejudice) may account for the fact that enrollment in Informatics has not dropped as much as it has in other sciences in recent years. At the same time, most departments have not compromised: their academic mission remains that students are educated to the levels of current research, and professors like to see them as the next generation of scientific researchers. We can't go for less, at universities. Academic requirements will not put students off but, to attract them, it must be tied to appealing visions in which they like to invest themselves.

⋆ *Informatics is* not *a science like physics or mathematics but a field of engineering and of programming.*

Informatics nowadays is a balanced field of both theoretical, experimental and applied endeavours and a science in every respect! Yet there continues to be a struggle in people's minds about the exact nature of the field. This reflects adversely on the information about Informatics given to prospective students, luring them with the marvels of modern ICT systems *that exist* but not with any great issues ahead for which we need their inventiveness. Already in secondary school, Informatics tends to be limited to the practice of information processing with PC's rather than as a field of fundamental principles and insights for science and society.

⋆ *The challenges of Informatics are widely understood and students are naturally attracted by it.*

Interestingly there does not seem to be a uniform opinion on what Informatics entails. Computer scientists tend to have a different view of it (and have different views of the field among themselves) than IT professionals. Certainly 'computing' and 'computers' are part of it, but the view that this characterizes the scope of Informatics seems obsolete. Students (nowadays) grow up with computers and software as a normal technology and can't see why it should be anything special to study it, they often have different motives which we fail to capture. Certainly 'programming' is no longer perceived as the heart and soul of the field, but rather as a means towards a higher end. If 'we' can't tell what Informatics is about really without painting ourselves in a corner, how can we expect others to know it and students to be grabbed by it. One reason why e.g. game design and -programming is now quoted as having positive effects on enrollment is that it represents a class of hard computing problems that appeal to students naturally as a complete domain that requires human ingenuity and creativity rather than software that simply exists.

⋆ *Informatics is tough and you have to work very hard in it, and students have to be good in mathematics in order to make it in computer science.*

The notion that university studies in the 'sciences' are harder than e.g. studies in law or social science is well-known and persistent for many years. There is no reason to believe that Informatics is perceived differently. Students who shy away from the sciences for this reason will not easily be convinced otherwise. But the fact that a discipline is challenging and requires dedicated study does not turn students away by definition, as long as they see that it will be interesting and (intellectually) rewarding or just plain 'fun' to do it. However, while all professional computer scientists will say that the discipline *is* rewarding, this is not the first impression many young people seem to get when they see our curricula or hear us explain what the field is about. The claim that you have to be 'good in mathematics' in order to be 'good in Informatics' is fully outdated and misleading. The nurdy image, which is totally false but persisting nonetheless, is not encouraging either.

> ⋆ *Despite many serious attempts to attract (more) female students to Informatics, the results are very limited in most countries. The level of interest among women for Informatics and science studies in general seems culture-dependent and is not influenced by advocating IT to them and by the great job opportunities.*

The interests of female students tend to go further than 'single track' programming-oriented computer science, they are 'multi track' persons and like an open and creative discipline with all its design- and user-related challenges in real environments. This is very different from the image (young) people often associate with Informatics and, even worse, with Informatics studies at a university, the image of a field dominated by 'pale-faced guys spending the whole day behind flat screens'.

> ⋆ *Women will be attracted to Informatics when they see how interesting and creative it is to build websites.*

Even if most women tend to like creative disciplines, this does not mean that they are only attracted by the soft side of Informatics; indeed, creative aspects of the field can be found within as well as outside the research world, and include all design issues like new algorithms, new models and methodologies, and so on, which are apt to stimulate the logical side of women's skills.

> ⋆ *Students believe Informatics is risky because they fear that all IT work will be outsourced by the time they graduate.*

The great impact of IT on businesses and the economy at large, including the ups and downs of computer firms and the whole new order of outsourced and offshored software production, is both an asset to the field and a cause of unsubtle publicity that is often perceived negatively. *If programming is the heart and soul of computing and is being auctioned off to the highest offshore bidder, what is the future for me?* (Denning and McGettrick). Over the years the demand for university graduates in Informatics has only grown and the industry need is higher than ever, but this fact seems to vanish in the public eye when newspapers report on all the banks and businesses that offshore their ICT divisions to places in other parts of the world. Outsourcing is a complex phenomenon but a normal development in the global economy (Friedman). Many IT companies are genuinely global organizations too and fight skills shortages in one place by looking for them elsewhere, constantly adapting their business model. Overall the development only leads to more higher-level jobs in IT, which are precisely the jobs university graduates are (or: *should be!*) trained for.

> ⋆ *There are many exciting informatics-related subdisciplines in other sciences now, causing Informatics itself to suffer greatly in attention.*

The development of separate curricula in applied informatics fields, artificial intelligence, bio-informatics, computational science and other growing and glowing areas has undoubtedly kept many highly qualified and motivated students away from the core discipline of Informatics itself. Indeed, students interested in Informatics 'no longer have to major in the field to explore programming and modeling' as noted by Furst and DeMillo. At the same time the core discipline of Informatics may have taken too restrictive a view of itself, leading people to view it as a service science for using information technology instead of knowing better and developing its own scientific image.

2.2 Bachelor vs Master Enrollment

> *Computer science curricula are old, stale and increasing irrelevant. Curricula needs to be vocational, and divergent, widening the computing student's view of the world, not creating a sterile bubble, closed off from the wider issues in the world, and from the networking, the integration, the global reach of computers. There is a need for a drastic rethinking of what the discipline is about. There is a need for new curricula which represents a real paradigm shift [..].*
> N. McBride (2007).

The enrollment problem immediately translates into the question of how to motivate and attract more young people to university studies in Informatics. There clearly is a difference between motivating and attracting prospective students for Bachelor studies in Informatics and motivating and attracting (experienced and informed) Bachelor students for Master studies in some Informatics domain. Prospective Bachelor students (in secondary school) have had very little exposure to 'serious' Informatics (but plenty of exposure to the products of the field on their PC), are full of ideas of what they find interesting and like to know or explore (Physics, Psychology, Law, ...), and have many options for university studies that cater to their interests. Students want to go where their interest, their eagerness to learn is leading them. It is understandable that this group is often approached by pointing to the impressive developments in the field, hoping that it will make a difference and interest them for a Bachelor study (and a future) in Informatics rather than another interesting field.

Actually, in choosing a bachelor program, secondary school students are often motivated by the enthusiasm for a particular teacher and his/her discipline and by the professional image of the field perceived in society. Since what we have called here 'serious Informatics' is not a classical secondary school subject, no support comes in the Bachelor's enrollment from good school teachers, who tend to transmit enthusiastic views of their own disciplines only. Here are some typical examples of how Informatics is described for prospective students:

> *At every step of our world's move to an information society, key solutions are provided by computer science, also known as informatics: the science of processing information through computer programs. At the heart of cell phones, airlines and airplanes, financial transactions, company management, publishing of any kind, the internet and world wide web, industrial plant control and all other devices and processes that make today's world run, lie algorithms and data structures devised by computer scientists. No other discipline has grown so fast in such a*

short time, and none has better prospects for its graduates in a world that does not cease to find new uses for information technology. Computer science offers a unique combination: scientific and engineering appeal; the growth prospects of a multi-billion dollar industry; and the ability for individuals to make a difference.
From: 'Why Computer Science', Dept of Computer Science, ETH Zürich.

Computer science is concerned with information and performing operations on information. Therefore computer science is a broad subject. Although relatively new, the field of computer science has become a rich and interesting science. The bachelor courses [...] cover a significant part of that field: computer systems, software engineering, formal methods, artificial intelligence, business informatics, business mathematics, bio-informatics. We are looking for strong and motivated students for our bachelors computer science, artificial intelligence, and information sciences. [...] It depends on your preference which bachelor is most suitable for you; further specialization follows in the masters. It is hard to imagine life without computers. All computer science bachelors prepare you for a broad spectrum of jobs. Do you wish to know more? Consult the webpages for our bachelors, or meet us at one of our events or open days!
From: website Dept of Computer Science, Free University, Amsterdam.

Is this an effective way of solving the enrollment problem in the long run or are other visions needed?

Enrollment at the Master level is less seen as a problem at this stage of the unfolding of the Bachelor-Master system in Europe. Prospective Master students have a better feel for the original, deep scientific challenges of modern Informatics and the changing paradigms of new systems to serve the understanding of nature and the benefit of industry and society.

However, industry complains that the numbers of graduates coming from the MSc programs in Informatics are way too small for its needs and universities and funding agencies tend to be slow movers when it comes to recognizing Informatics as the science of the future and thus to invest in growth at this level. Yet many new developments are appearing in the expanding range of MSc programs in Departments of Informatics/Computing all over the world. Some typical examples are the following:

The Department of Computer Science and Engineering is strongly international, with 76 faculty and 55 PhD students from 30 countries. It provides a dynamic research environment and has groups of world renown in a number of fields. The research spans the whole spectrum, from theoretical underpinnings to applied systems development. We have extensive national and international collaboration with academia and industry. Industrial collaborators in Sweden include Volvo, Saab, Ericsson and Saab Ericsson Space, as well as the many smaller IT companies associated with Chalmers. New Master's programmes at Chalmers 2007:

- *Integrated Electronic System Design*
- *Secure and Dependable Computer Systems*
- *Foundations of Computing: Algorithms and Logic*
- *Interaction Design*
- *Networks and Distributed Systems*
- *Software Engineering and Technology.*

The externally focused research environment at the College of Computing encourages cross campus, multidisciplinary collaborations that significantly increase opportunities for true innovation in all fields. We offer several exciting graduate options representing our vast range of world-class faculty research and broad technological expertise. Masters degrees offered by the College of Computing:

- *Computer Science*
- *Human-Computer Interaction*
- *Information Security*
- *Bio-engineering*
- *Robotics*
- *Computational Science and Engineering.*

(Quotes from websites)

A hidden but serious impediment here is that Informatics as a broad field of scientific and technological endeavour, despite its pervasiveness, is often not fully recognized in the public and scientific 'eye' as the leading science of this age. Paradoxically, in university environments the decision to invest in (the development of) Informatics, if at all, is seldomly taken out of scientific motives but more often by the pressure of student-staff ratios and through general measures of which other disciplines benefit more. Application domains in other disciplines like e.g. bio-informatics, chemical informatics and so on are often better recognized and appreciated, giving *context* which Informatics by itself does not provide, and yet the core issues often are generic Informatics problems in modeling complex systems in information processing terms and e.g. in combining data analysis techniques and system simulations with novel graphical visualization techniques. In various sciences, like Physics, people are beginning to realize the great value in the concepts, techniques and results from Informatics. This is now developing rapidly in fields like Economics and Biology as well. The synergies of Informatics/Computing with almost any other field of science often lead to remarkable results, which can be highly motivational for the core disciplines involved including Informatics itself, if the novel contexts are embraced (as is increasingly done in MSc programs in Informatics). It is a prerequisite for not loosing grip of the development of our own science.

2.3 Pre-university Informatics

(Karl Posch/Jan van Leeuwen)

While we focus mostly on the problems of university level Informatics curricula, it is often argued that the key to the enrollment problem in Informatics is the inadequate, or even lacking attention for the discipline in *secondary* education. Clearly these aspects are all intertwined: if an adequate view of the discipline is lacking at the university level, we cannot expect the situation to be much better at the secondary level either. The *Computer Science Teachers Association* found in 2006 that only 26% of US schools require students to take courses in Computer Science, i.e. in 'Computers and Problem Solving', despite the fact that 'computers pervade nearly every aspect of our lives'. Lack of time in students' schedules is cited as the reason for declining enrollment in high school courses. It was also observed that "Computer Science education is plagued by public misperceptions including students' thinking that it is all about playing video games and surfing the Internet." Do we have the right alternative views to offer for these youngster in the *K-12* range that can help them 'acknowledge Computer Science as the fundamental field that it is' and prepare them for 'the needs of our technology-driven society and workforce' in the future?

In a recent study, Blum and Cortina (2007) identified the following reasons for the decline in enrollment in CS courses and programs at the high school level in the US:

- *outsourcing reports in the media*
- *dot-com bubble burst/not enough high paying careers*
- *increased amount of required courses and tests*
- *elective status/competition with many other electives*
- *lack of understanding of CS by guidance counselors and administrators*
- *ill-prepared teachers/lack of interest*
- *difficulty of material/not 'fun enough'*
- *irrelevance to students*
- *male-dominated discipline*
- *lack of meaningful curriculum and standards*

They conclude correctly that 'high schools need considerable help to motivate students to study computer science'.

The situation in Europe is not much better but vastly differs from country to country. The problem is not only the very limited time for Informatics in the school schedules as compared to e.g. mathematics or physics, but also the lack of good standards for content ('what should we teach'), textbooks ('how do we describe it') and didactics ('how should we teach it') at this level. There are many good initiatives but the emphasis tends to be on introducing pupils to the elements of MS software, computers, problem solving and programming. This is like teaching mathematics and aim it at the ability to calculate, and it reminds of E.W. Dijkstra's well-known aphorism: 'Computer Science is no more about computers than astronomy is about telescopes'. If the discipline isn't just about programming, then what are the other careers that an education in computer science prepares a student for? And, do we have the teachers for it?

Taking the Austrian situation as an example, the problem is that there are by far not enough trained informatics teachers. The reason for this seems to be the long history of too many unemployed teachers or teacher candidates (coming freshly from university). Due to this, the start of running university programmes to train informatics teachers was delayed by the Austrian government (which was in charge of defining installations of university programmes at individual universities until 2002). The schools rather employed 'self-educated' teachers (trained in other subjects) for informatics. Although these teachers have usually been highly motivated, they do not have common background knowledge, but rather teach what they like about informatics.

This situation seems to be a key factor for the lack of students enrolling in informatics bachelor programmes. Self-trained teachers usually got involved into computers (as their hobby), and not into informatics. They also quite often were struggling behind computer kiddies, who knew a lot more about certain trendy topics. All too often, teachers thought that programming was the core of informatics: *programming a computer was the main thing.* Too often they only worked with toy examples, and not with a systematic approach to problem solving. Whatever they have acquired as a skill – be it Java programming, web-page editing, spreadsheet manipulations, text editing, or the like – after not too long all these hypes became standard skills and were not considered fancy anymore by the kids.

Indeed many school teachers do not realize that there is any crisis in the discipline at the Higher Education level. Good students are often turned away by the instruction they receive at aged 12 or thereabout and are not introduced to understand the broad area of applicability of computers. Moreover informatics/computing is often (usually) not seen as being important like mathematics or physics. If we believe computing is important, then that view needs to change. But the universities need to help the high schools to elevate computing to be a discipline of the first rank.

Self-trained teachers have been typically not able to communicate 'informatics' as a means to 'invent new worlds', or as a science of structuring and solving problems. They are not to blame for not having been able to introduce 'fundamental ideas of computer science', since this has not even been agreed upon in the computer science community itself. As immigrants into informatics, they have been fascinated about the possibilities of using a computer, and mastering this complex thing. With this skill, they got recognition from their fellow teachers, but were also feared by them. Fear of the fellow teachers increased in the 1990s when all schools connected to the Internet. The teachers tried to master network technology and became the school's system administrators. Suddenly 'computers on the Internet' were getting all the attention, and also more and more financial resources. Naturally, this became a threat to the established teaching subjects, and also a threat to the teachers of these. The sheer unlimited possibilities of this rapidly rising topic came to a halt with the clash of the internet bubble. Suddenly, everyone blamed informatics for having promised too much. Of course, this was the time for fighting back by the long-term established groups. Even in 2005, long after the internet bubble has collapsed, there were teachers who were still arguing against informatics in school using the example of the Internet bubble. They have not noticed, maybe did not want to notice, that this downturn has long been over.

Meanwhile, in 2007, we still do not have adequately educated informatics teachers in Austria in numbers. So the problem will live on. Together with the changed views that young people have of the field, this seems to contribute to the enrollment problem considerably.

2.4 Pre-university Informatics and Computer Literacy

In some countries, e.g. the UK, early courses in Computing tend to take the form of courses on computer literacy, and so address such matters as wordprocessing, spreadsheets, et cetera. Such courses are typically taught by the Informatics teacher. Naturally pupils then make assumptions about the nature of study about Informatics which may adversely influence their view of the deeper aspects of the field. There are many issues that stem from this:

- should there not be a clear distinction between computer literacy and (introductory) Informatics?
- should pupils not be told about the wonders of computing at age 12 or thereabouts so that they can make informed choices about their future study?

- what aspects of Informatics should students be exposed to at high school level?
- how can we articulate these issues clearly to pupils and their parents? And, of course, to teachers?

Computer literacy itself perhaps needs to be looked at again in the light of pupils' likely familiarity with the iPod, MP3 players, mobile phones, Internet, and so on. Indeed it should be recognised that such courses will need to be continually upgraded as computer and information technology evolve.

2.5 Discussion

The challenge in the enrollment problem is the challenge of creating a greater influx of well-motivated, talented, creative students who take it on face-value that *thinking Informatics* is the best alternative among many possible university studies. The problem is not the students but us: the world is becoming so IT-driven and the system paradigms in computing are so radically changing time and again that our curricula are not keeping pace. Are the skills and insights we teach really the skills and insights the prospective students feel they want to know, given their vision of the future of IT? Is Informatics intellectually challenging to them by its intrinsic scientific questions, by its technological innovations, the benefits they see for mankind? If the job market argument does not impress them, then what will? Are they buying what we tell them? Do we know our potential students?

> *If the gap between public knowledge and academic curriculum isn't large enough, the gap between academia and industry practice is a gaping hole. While academic departments concentrate on developing new computer [and software] systems in an ideal organisational environment, a lot of industry has moved away from in-house development to a focus on delivering a service. As commercial software products have matured, it no longer makes sense for organisations to develop software from scratch. Accounting packages, enterprise resource packages, customer relationship management systems are the order of the day: stable, well-proven and easily available. IT departments now focus on contracts, tenders, service level agreements, training, system usage and incident management. Interrupts, loops, algorithms, formal methods are not on the agenda. IT is about deploying resources to meet the information needs of its customers. Implementation, facility management, systems integration, service management, organisational change even environmental audit are the language of IT. These hardly feature on computer science courses.*
> N. McBride (2007)

The question of marketing Informatics effectively is nontrivial and may at the same time not be the complete answer. A field like Astronomy is often cited as an inspiring example. Does Informatics have the same appeal? Great developments in the context of the Web and the rise of companies like Yahoo and Google are catching everyone's attention and have enormous value for the indirect appreciation of Informatics. Are we telling prospective students about the exciting developments under Web 2.0 and 3.0 and the great trends in the domain of Computing? IT is changing the world but it has not stuck in people's minds that the science of Informatics is behind this and that it takes great minds like in any other science to develop it further.

3 New Approaches to the Enrollment Problem

> *Computing has permeated and in many cases transformed almost all aspects of our everyday lives. As computing becomes more important in all sectors of society, so does the preparation of a globally-competitive US workforce with knowledge and understanding of critical computing concepts, methodologies, and techniques. Unfortunately, despite the deep and pervasive impact of computing and creative efforts in a small number of institutions, undergraduate computing education today often looks much as it did several decades ago.*
> CPATH Program Solicitation (2006).

(Simon Thompson/Jan van Leeuwen)

This section covers a number different approaches and examples to raising the profile of CS. It is meant to give an impression of the different ideas that are pursued in CS departments everywhere.

Is CS the problem or the solution? One view is taken by Eric Roberts proclaiming that computer science trouble lies in education, not jobs. A recent article on the website of the British Computer Society entitled *The Death of Computing* caused a furore in the UK when it was published in the UK's HE magazine. The article suggested that the current curricula in Computing are way past their time. A rebuttal suggests that the claimed demise of computer science has been exaggerated. There's also a heated debate about whether girls need something special and 'girly' to encourage them into Computing/Informatics.

At many departments around the world the enrollment problem continues to stir up debates. Explanations are sought but seldomly found. Controversy abounds as to the best way to tackle the problem. New approaches are tried and experiences learn what seems to work and what does not.

3.1 Working with Schools

How can we convey the excitement and intellectual challenge of computer science to school children, when their first impression is of learning 'information technology' consists of office applications, whilst their home experience is of YouTube, MySpace and other Web2.0 applications?

Some departments take a publicity-led approach; notable in the UK is the *cs4fn* ('Computer Science for Fun') initiative at CS at Queen Mary - University of London, which has seen a dramatic rise in student applications in recent years. Others are looking at ways of developing innovative tools, such as *Game Maker* and *Greenfoot* to teach programming in a games context.

There are a number of worldwide competitions for schools. Particularly laudable is the *FIRST*

LEGO League which introduces children around the world to the fun and experience of solving real-world problems by applying math, science, and technology: specifically through building LEGO robots.

Our best ambassadors are our students, and many universities encourage students to go into schools to raise the profile of CS. Some give them credit or recognition for this work.

Professional organizations take very commendable initiatives also. For example, ACM has developed very interesting and informative brochures with many examples of issues in computer science and of the choice of computing disciplines within the field (*Computing Degrees and Careers*). The accompanying website gives attractive vistas of the Informatics/Computing field for prospective students and of what 'computing professionals do'.

In some countries industry is developing initiatives aimed at schools as well (like KPN and the software companies joined in *ICT Office* in the Netherlands), to help them in developing ICT courses, to give a view of the industry challenges, and to propagate Informatics among youngsters as a clear 'investment' in the future (think of the Microsoft slogan 'new skills lead to tomorrow's inventions').

3.2 Contests and competitions

Students and prospective students can be immensely motivated by contests that challenge their skills. Students like sports and games and often join if only for the fun of it. In the meantime they become acquainted with the challenges of the field and, not in the least, with other students who share the same interest.

For prospective students there are the Informatics Olympiads, e.g. the British one but there is also the International Olympiad in Informatics. In fact, many countries organize national Informatics Competitions e.g. as pre-rounds for the international Olympiad. The main computing and software companies run competitions for students as well: IBM run a variety, as do Google (the 'Google code jams'), Microsoft (the 'Imagine Cup'), and Sun Microsystems.

For students there is the annual ACM Collegiate Programming Contest, with its regional prerounds. At many universities there are local pre-rounds (like 'the Utrecht Programming Championship') which draws quite an interest from students, not only from Computing. The contests require good programming skills but, usually, even greater skills in *problem solving.* Computing students often find out that they are good in the former but need 'more training' in the latter.

There are also contests that aim at more advanced or specialized students. An example is the ICFP Programming Contest (see `http://www.icfpcontest.org/`), a programming competition in the area of *functional programming* held every two years and which began already in 1998.

There are now also special contests aimed at female students. A well-known example is the *Games 4 Girls Competition* (G4G). In this competition, teams of up to five college women are challenged to create computer games specifically designed to be fun for (middle or high school age) women. The entries are judged by professionals and high school girls. The award for the winning team is $ 1000 per team member, for the second and third place teams it is

$ 500 per team member.

3.3 Industrial links

Departments increasingly advertise that Computing/Informatics students may be engaged in real IT tasks 'in practice' in a range of companies, in small projects during their bachelor studies or indeed in larger projects during their master's. It should motivate prospective students that their studies have a concrete future in challenging jobs.

For example, employers are increasingly trying to recruit students into industrial placement programmes, known as 'sandwich' programmes in the UK. Indeed, Intel in the UK only recruit graduates who have been on a one year placement with them. In the Netherlands, many MSc students in Informatics or Information Science do their MSc thesis 'in house' in a software company or an IT consulting firm, or in another type of organization where they can study and learn the complexities of designing and developing novel systems for companies.

Other universities aim to give students real experience within the university: standing out among these in the UK are *Genesys Solutions* at the University of Sheffield and the *Kent IT Clinic* at the University of Kent.

Conversely, industries increasingly invest in (helping in) the education and training of students in schools at all levels as well. An example is found in Microsoft's EMEA initiatives ('Europe, Middle East and Africa region'). At the top level there is e.g. the European Science Initiative by Microsoft Research, 'a multi-year programme for collaborative research at the intersection of computing and the sciences, focused on new computing paradigms, computational science and intelligent environments'.

3.4 Reinventing the Curriculum

3.4.1 Course level

Many CS departments realize that they can't go on teaching the traditional subjects in the old-fashioned way. Students are more knowledgeable about IT than a decade ago and they are not satisfied any longer by courses that ignore this. Curricula now increasingly choose for courses that embed students in real world problems rather than toy examples. The dictum is:

> *... computer science, as it is practiced in the business world today, is about application-based problem-solving for specific objectives; in terms of students' career prospects, it makes sense that computer science education reflect the reality they will face after graduation.*
> `http://cse.unl.edu/reinventCS/` (2007)

Following this tendency, many universities have introduced new programmes or are totally renewing their current program and approach in Computing, including

- the introductory *media computation* course at Georgia Tech (Tew, Fowler and Guzdial).
- the *ReinventCS Project* at University of Nebraska-Lincoln (UNL), see `http://cse.unl.edu/reinventCS/`.
- the redesign of the first-year programming core in CS at Rochester Institute of Technology by means of a *Multi-User Programming Pedagogy for Enhancing Traditional Study* environment, based on the programming of objects in a virtual worlds, see `http://muppets.rit.edu/muppetsweb/about/`.
- entirely new curricula at many European Universities in applied domains of Informatics e.g. in *Information Science* (in the Netherlands) or *Wirtschaftsinformatik* (in Germany) that complement the traditional course programs, often very successfully so.

One of the issues in all these examples is to find the best context in which the fundamental principles of the field are taught (including a re-appraisal of what these principles are). The 'concept-in-context' approach seems to be taking over in many courses and curricula. An interesting example is the proposal for an *innovation-oriented* Informatics/Computing curriculum by Denning and McGettrick. Other curriculum proposals aim at specific sectors, e.g. the *creative industry*.

In the European context, many courses and course programs in Informatics/Computing have been and are being redesigned as part of the gradual change-over to the unified Bachelor-Master system since 2001.

In the US, the CPATH program of the *National Science Foundation* explicitly aims to stimulate the transformation of 'undergraduate computing education at a national scale, to meet the challenges and opportunities of a world where computing is essential to US leadership and economic competitiveness across all sectors of society'.

3.4.2 Curriculum level

There are many efforts to re-think the overall composition and direction of the undergraduate curricula. Innovations concentrate on building interdisciplinary undergraduate and masters programmes, particularly with the sciences. But even within IT, many developments occur.

Twenty years ago it was possible to think of a single computer science curriculum. Now ACM offers a variety of curricular suggestions `http://www.acm.org/education/curricula.html`, including Computer Science, Computer Engineering, Information Systems, Information Technology, and Software Engineering. Indeed, many CS departments have 'diversified' in the past years and offer several of these curricula instead of 'just' Computer Science only, in an attempt to cater for the changed interest of students in IT.

In the UK, there is one so-called 'subject benchmark statement' for all cognate programmes, `www.qaa.ac.uk/academicinfrastructure/benchmark/statements/computing07.asp`. The single statement is achieved by aiming for an over-arching umbrella for programmes in this area, and is achieved by attacking the problem from the top down, looking at skills and competences first, rather than specific areas of knowledge. The benchmark statement refers to the recommended subjects for the bachelor's degree with honours and gives one way of upgrading and modernizing curricula.

A leading example of how Bachelor programs can be modernized and re-targeted is the redesign of the undergraduate program at the Georgia Institute of Technology. The CS program there now consists of eight *threads*, each related to a particular 'vista' of the IT domain.

> *Threads concentrate the general subject of computer science along eight distinct, logical perspectives – a viewpoint on the field, and a goal for achieving expertise. Each of these perspectives is associated with a set of courses, from introductory courses through to specialized senior-level courses, from computing and other fields, where these courses will lead to a students' expertise in that slice of computing.*
> See: `http://www.cc.gatech.edu/education/undergrad/bscs`.

> *Threads represent a departure from a vertically oriented curriculum whose goal is the creation of students with a fixed ste of skills and knowledge. [...] A thread is a fundamentally horizontal idea whose goal is to give students the broad collection of skills and learning experiences they need to thrive in the globally competitive Conceptual Age. A thread provides an intuitive, flexible and mutually strengthening set of courses that allows a student to craft his or her own distinctive future.*
> M. Furst, in: Th.L. Friedman, The World is Flat (2005/2006), p 313.

The eight threads at Georgia Tech include: *Computational Modeling*, *Embodiment*, *Foundations*, *Information Internetworks*, *Intelligence*, *Media*, *People*, and *Platforms*. Students need to take two threads of their own choosing in order to graduate, thus giving them the freedom to follow their own perspective of the field.

An even more far-reaching initiative has been the highly original approach and curriculum by the IT University of Copenhagen, see `http://www1.itu.dk/sw5211.asp`. The university was set up with a very original vision of graduate education in Informatics and proves to be very successful. The university started its activities in 1999 and now offers Master programmes in 'Media Technology and Games' and 'Software Development and Technology'.

3.4.3 Underlying Philosophy

The underlying and unique philosophy of courses in Informatics/Computing, often characterized simplistically as 'problem solving' only, is also receiving more attention now. The common view now tends to *algorithmic thinking*, popularized under the name 'computational thinking' in a recent CACM-paper by Jeannette Wing.

> *The main characteristics of algorithmic thinking include:*
>
> - *algorithmic thinking including recursive, distributed and parallel possibilities and attention to the benefits and the limitations of these; the role of these in devising approaches to areas of system design, problem solving, artificial intelligence, simulation and modelling*

- *recognition of the relationships between the concepts of specification, program and data (in all its forms), as well as the power of the notion of transformation and proof, and the place of these in computing*
- *understanding the power behind abstraction, the potential of multiple levels of abstraction and the role this plays in computing*
- *understanding the opportunities for and the potential of automation, but also the proper balance between automation and how humans effectively interact with computers*
- *recognising the role of redundancy, diversity and separation of concerns in achieving reliable, safe and critical systems - often in the presence of uncertainty - and approaches to achieving this*
- *recognising simplicity and elegance as useful concepts and principles on the one hand, but also bad and dangerous practices on the other.*

Subject benchmark statements Computing (2007).

Furst and DeMillo describe a new philosophy called *symphonic thinking* which they claim to be essential for our Informatics/Computing graduates as well. They have used it in designing the new paradigm of 'threads' for undergraduate education in Informatics/Computing.

Chances are that our curricula in Computing/Informatics will look very different from their current versions in even less than five years from now.

3.5 Grand Challenges in Education

In the UK, McGettrick *et al.* initiated the idea of identifying 'grand challenges' in computing education at the university and pre-university level. A grand challenge is to be seen as 'a major goal whose attainment will lead to significant improvements in the educational processes associated with Computing'. Among the challenges we find e.g. the following:

- *promote an improved and ultimately very positive public image of computing, ensuring that the public gains respect for the field and the professionals who practice it.*
- *rationalize the situation at the pre-university level and direct it towards the promotion of computing to would-be students of computing. Create for students a smooth transition from school to university by enthusing and informing potential students and by creating a positive influence affecting pre-university computing.*

These challenges are directly related to the enrollment problem (where 'computing' should eventually be replaced by 'informatics' as the better term for the field). One of the forms a challenge could take is e.g. 'to explain to a 12-year old the main challenges facing the Informatics community'.

4 Perspectives and Challenges for Students

The reasons for studying computing are as diverse as its domains of application. Some students are attracted by the depth and intellectual richness of the theory, others by the possibility of

engineering large and complex systems. Many study computing for vocational reasons or because it gives them the opportunity to use a creative and dynamic technology. Whatever the perspective, computing can claim characteristics that, while present in other disciplines, are rarely present in such quantities and combinations. Besides being ubiquitous and diversely applied, computing promotes innovation and creativity assisted by rapid technological change. It requires a disciplined approach to problem-solving that brings with it an expectation of high quality; and it approaches design and development through selection from a wide range of alternative possibilities justified by carefully crafted arguments based on insight. It controls complexity first through abstraction and simplification, and then by the integration of components. Above all, it is a product of human ingenuity and provides major intellectual challenges, yet this limits neither the scope of computing nor the complexity of the application domains addressed.
Subject benchmark statements Computing (2007).

(Letizia Tanca)

People who are responsible for Computer Science and Informatics courses are continuously facing the problem of attracting students to their curricula, while there has been a dramatic decline in enrollment in the last few years. Often, the messages the students receive from the educational institutions, along with those coming from the society in general, dispose them to see the field in a very narrow perspective, which contributes to keeping the best students far from the computer science courses.

We believe that the emphasis should not be on 'correcting' the current opinion of computer science studies, but on 'enlarging' the view of what can be achieved by attending and graduating from them. In this respect, we should convey the message that various types of personalities can be accommodated within the computer science curricula, provided that they feel that their main aspirations be fulfilled. Among the students' aspirations we should not only include the technical ones, such as the possibility to engage oneself in a difficult and challenging discipline, or to hack in cyberspace, but also personal and social aspirations, both during the studies at the university (like the desire to be exposed to the teaching of high level scholars or simply to feel at one's ease within ones class) and in the personal life and the later career after graduation.

As part of the general enrollment problem, a very much felt gender problem also arises: indeed, while the number of students applying for, and remaining in, computer science courses is decreasing, the number of women among them is decreasing even more rapidly. A special train of thought must thus be devoted to this datum, as the Informatics discipline might otherwise remain too much within the control of the male gender, preparing itself to being deprived of the unique contribution to creativity given by the mere existence of diversity.

Another important problem hides in the kind of students who have been enrolling in Informatics courses in the last ten years. Indeed, while we perceive our discipline as a challenging, logic-oriented one, where mathematical skills are required, our courses tend to attract people who are fascinated by the technological possibilities offered by the applications of Informatics, but do not feel the need, for the initiated, to dig more deeply into its roots. Hence the need to attract more people 'of the right kind', by which we mean people with (at least a small) mathematical bent or interest.

On the other hand, a somehow opposite problem concerns the lack of confidence of some students, who believe in the legend that only exceptionally intelligent fellows will be able to carry on with the scientific studies. This kind of students should be encouraged if they are sufficiently driven by a genuine interest in scientific and technological studies, since motivation to formal thought, accompanied by adequate work, may equal the results obtained by talent.

4.1 The Popular vs. the Broader View on Informatics

The popular view of Informatics is that of a very technological discipline, devoid of conceptual challenges. Thus often the lovers of mathematics and formal sciences tend to be a bit snobbish about it. Of course this is blatantly wrong, but it nevertheless has an adverse effect on students. In the following I list some important considerations which should guide our attempts to make the discipline more interesting for young people. In particular, I address the various facets of Informatics, which might unveil its appeal for different kinds of prospective students.

- Informatics seen as a 'mathematical game', a challenge for intellectuals → feeling 'a high IQ person'.
- Informatics as a way of creating patterns, in a similar way as some people say that mathematics is the science of patterns. The patterns Informatics deals with can be numerical, spatial, temporal, and even linguistic. And through visual and written forms of expressions, Informatics is connected with mathematics to develop skills for thinking clearly, strategically, critically, and creatively → use of mathematical models to represent and produce changes in both real and abstract contexts.
- Informatics as a discipline for problem solving, through the education in knowledge representation and processing → use of symbolic forms to represent and analyze real-world situations and structures.

  > *Computing is a discipline that offers rewarding and challenging possibilities for a wide range of people regardless of their range of interests. Computing requires and develops capabilities in solving deep, multidimensional problems requiring imagination and sensitivity to a variety of concerns.*
  > Reason 2 in: Top 10 Reasons to Major in Computing (ACM)

  > *Having a computing major will provide you with a foundation of knowledge, problem solving and logical thinking that will serve as a competitive advantage to you in your career, in whatever field you choose.*
  > Reason 6 in: Top 10 Reasons to Major in Computing (ACM)

  > *To think independently and creatively, carrying out their own in-depth studies as needed to address new situations in their work.*
  > (Denning)

- Informatics as the science that applies to other sciences → a good computer scientist is the one who tries to understand the internals of another discipline to which Informatics is applied. Examples are: Bio-informatics, Economics and Management Engineering, the informatics behind multimedia and image representation, et cetera.

> *Computing drives innovation in the sciences (human genome project, AIDS vaccine research, environmental monitoring and protection just to mention a few), and also in engineering, business, entertainment and education. So if you want to make a positive difference in the world, study computing.*
> Reason 3 in: Top 10 Reasons to Major in Computing (ACM).

4.2 The 'Engineering Aspect': Informatics as a Way to Make Things Happen

One of the interesting aspects of Informatics is that it can be classified as a scientific as well as a technological discipline. Indeed, as already said in the sections above, the methods of Informatics are similar to those of all scientific disciplines, since modeling and verification is the typical scientific research pattern. On the other hand, the objective of modeling reality in Informatics is to feed its abstract representation to a program, in order for this to act on it and generate new behaviors and tools. Thus, here we see the use of our knowledge of scientific laws (in our case of mathematics and logic) for producing new objects: this is a characteristic of technology, and of engineering in general. As a result, a computer specialist feels the usual elation of engineers at being able to *create*. Examples of typical application of ICT skills for building everyday objects, often used by young people, which can be mentioned to make Informatics appealing for them, are:

- the next generation of mobile phones, tiny media players, and palm computers, where the reduction of power consumption, and efficient routing, are problems for computer engineers, while compression algorithms and data reduction are tasks for the computer scientists.
- high-tech clothing: the insertion of RFID tags helps following the clothes story throughout the production and distribution cycle, as well as during its life after it has been bought, in order to collect information about its usage and consumption pattern.
- advanced medical tools, again, are a ground for computer engineers as well as for computer scientists.
- today's gaming machines (game-boys, play-stations et cetera) incorporate high-level computing technology: computer engineers produce powerful chips capable of processing 3-dimensional graphics, computer scientists produce algorithms for image and multimedia rendering, artificial intelligence gives us the ways to make the games ever-changing and multi-pattern.

Project-based competitions as mentioned earlier can stimulate and challenge students in their desire to build their own systems.

4.3 Motivating Initiatives for Fostering Informatics Studies

> *Creating high-quality computing solutions is a highly creative activity, and computing supports creative work in many other fields. The best solutions in computing exhibit high levels of elegance and beauty.*
> Reason 7 in: Top 10 Reasons to Major in Computing (ACM).

The 'narrow view of informatics' should be fought by cultural as well as by practical initiatives, in particular during the time students spend at the university. In the following I name a few initiatives that might be taken:

- Seminars, summer schools (for the best students), and conferences on different subjects should be fostered within the degree courses. This can be done either during institutional course hours or out of the course timetable. Such seminars could include: *(a)* mathematics/logic related problems in Informatics, *(b)* problem solving techniques that make use of representation/modeling techniques taken from the different areas of Informatics (e.g. Software Engineering, Databases, Artificial Intelligence, et cetera), *(c)* applications of Informatics to different disciplines, like Biology, for instance, *(d)* discussions related to the philosophy of science, *(e)* discussions related to social, legal and ethical problems in Informatics, and *(f)* challenging problems of the discipline, possibly working by examples if too difficult.

  Each of these events should be very open, with the possibility for the students to participate in and debate the issues at hand. Initiatives of the same kind could also be taken within the high schools. The university can propose, each year, a carnet of such events to the high schools, which could be able to choose a group of seminars for their students. This line of action has been pursued for the last two years at the Politecnico di Milano, and a large number of school has enthusiastically responded. Of course, it is too early to be able to provide figures about its impact.

- Some of the above subjects could also be included as institutional courses in the curricula, particularly in the MSc degree level. This is already done, for example, at the Politecnico di Milano, where courses on Philosophy of Science and the legal aspects of Informatics are present.

- Giving students the possibility to take part in national or international competitions like the British Informatics Olympiad or the International Informatics Olympiad.

- Again on the game side, local computer 'games' among the university students could be organized. A game might be: *(a)* the production of the best project, given a set of specifications (it should be a project which stimulates their imagination), *(b)* a computer game which requires Informatics skills to be pursued, and/or *(c)* a challenge on creation, where groups of students build an innovative system from an original idea of their own. Such experiments are carried out, for example, at ETH Zürich, where undergraduate students implement computer adventure and other kinds of games in Eiffel, using the Eiffelmedia framework.

- Study periods at, and visits to, company headquarters or production lines.

- Entertaining international relationships is a very valuable experience even for very young students. The current European initiatives, in particular the Erasmus (Socrates) project, are an excellent way to expose students to different ways of teaching and approaching the discipline. Other current initiatives consist in international protocols which set the seal for bi-directional exchanges between universities. All these initiatives should be enhanced – for instance by establishing special channels of exchange for master students within research projects – and also multiplied – by establishing many more agreements.

  Exchange initiatives should also be extended to US and other non-European countries. For example, the Computer Science Master Course at Politecnico di Milano has such an agreement with the University of Illinois at Chicago, and a similar initiative is currently about to be signed with GeorgiaTech. Of course these initiatives should be adequately publicized, in order for prospective students and families to perceive the appeal of a study course offering such possibilities.

- Devising *special programs* (e.g. honors programs) for talented or strongly motivated students. In this case, some kind of certificate, guaranteeing that the student has attended the special program, should be issued at the end of the studies. The most traditional way to implement such a program is to introduce additional, more challenging courses to the standard curriculum, and keep the group of students under control by allowing them to stay within the program only if a certain performance is achieved. Another, less common way to do it is to insert the students into a large interdisciplinary research project, collecting a number different professors in different disciplines, and assign small groups of students to the involved professors to let them co-operate towards a specific achievement within the project. Again, this type of initiative is only useful if made widely known to high school students and their families.

The given list of initiatives is obviously not exhaustive. Further initiatives can be devised.

4.4 The 'Hands-On Aspect' at the University

In conformity with the above, degree courses in Informatics/Computing should provide students with the possibility to *act*, besides studying. Theoretical courses are important, but only a part of computer science and engineering training. In order to appreciate the power of creation, students should be engaged in various kinds of other activities, including for example:

- attending 'project courses', already at the bachelor level, in which teams of students are required to cooperate and get organized to produce a medium-difficulty artifact. Such project courses could be either associated to a specific theoretical course (e.g. 'database project') or to a group of courses (e.g. a 'database and software engineering project'). In the latter case, also the contributions of the different sub-disciplines within the same projects are shown, proving that Informatics should never be considered as a set of non-communicating areas only. In general, isolated and far-fetched toy examples should be avoided.

- being involved in research projects with faculty members or PhD students, mainly during the master studies, but possibly already during the bachelor studies.
- getting in touch with other students and teachers from different disciplines, to get the feeling of the interdisciplinarity of Informatics (see below).

The project courses and research projects should propose new problems that are as challenging as possible, in order for the students to feel they are able to do things they could never dream of. For example, at the Politecnico di Milano, the AI and Robotics group designs robots which play soccer, and participates each year in the ROBOCUP international contest `http://www.robocup.org/`.

4.5 Women in Informatics

> *Are computer programmers from Mars? Is computer science a guy thing? Some experts are wondering just that at least, as it is taught now. [...] Some women who have been successful in computer science, however, say that is nonsense. What is needed, they say, is more social support for women in the discipline and for peers and parents to stop telling girls that computers are not for them.*
> S. Carlson (2006)

Female enrollment is a problem within the problem, since the decreasing rate of the number of women applying for Computer Science courses is even higher than the overall one. The following is also remarkable: the number of enrolled women abandoning the courses is higher than the number of abandoning men as well. These two pieces of information stimulate interesting lines of thought.

First of all we should realize that, on the average, women have different motivations and interests for studying than men. Indeed, rather than enjoying computers for some kind of 'hacking pleasure', more women than men are interested in other disciplines as well. Thus their special interest in Computer Science is often connected either to its application to other fields like Medicine, Social Sciences, Astronomy and so on, or e.g. to its strong connections to Logic, which often attracts them despite the prejudices about the so-called non-logical aptitude of women.

The second issue concerns a point we already made above: the stereotype of the computer science expert as a *geek* obsessed with computing, causes several broad-culture oriented students, among which many women, to disown their interest in Computer Science.

Third, female students do not often have a deep experience of computers before coming to the university. This may entail two consequences: *(1)* it is more difficult for women to be accepted when applying to courses where the admission tests include Computer Science skills, and *(2)* the women's self-confidence during their university studies is threatened by their continuous comparing themselves unfavourably with their male schoolmates, thus provoking them to decide to transfer out of Computer Science.

The first two points above are related to the fact that women are more likely than men to try to find an equilibrium in their lives among all the multiple interests they have. One of these is on the socio-emotional side, where also their relationship with teachers becomes an issue.

More women than men arrived in college with the expectation of establishing a personal relationship with faculty.
E. Seymour and N.M Hewitt (1997)

Thus, it may happen that a woman student, who finds the university environment, in particular the relationships with faculty, somewhat 'dry', is discouraged from continuing the Computer Science studies.

A very interesting piece of work, providing a deep insight in the problem, is the book *Unlocking the Clubhouse: Women in Computing*, in which social scientist Jane Margolis and computer scientist Allan Fisher study the reasons why computer science students are mostly male. Margolis and Fisher followed more than 100 computer science students at Carnegie Mellon University from 1995 to 1999. The book explores the gender-gap at Carnegie Mellon, and gives an account of a four-year social program with the goal to 'understand the experiences and choices of both men and women with respect to studying computer science, and to design interventions that would involve more women (A. Fisher and J. Margolis, 2002).

Among the initiatives taken at CMU, the authors quote the following as the most relevant ones:

- *monitoring and identification of transition points for (female) students, e.g. from introductory courses to upper-level courses,*
- *peer tutoring for (female) students in courses that are recognized to be particularly difficult,*
- *events especially designed for women.*

Actually we could say that the first two initiatives, although being designed as a consequence of the gender-gap problem, are surely interesting for all students whose confidence is somehow lower than the others.

4.6 Related Developments

Aside from female students, there are other groups of students with great potential in Informatics that may require special attention in some countries. The cultural demography of the young population in Europe is changing and so is the perspective of various groups among them on academic studies and what they expect of it for their future. In some countries there is a tendency among young people to prefer the curricula at the 'professional schools' (the Netherlands: HBO, Germany: Fachhochschule) that cater more to their interest or ambitions instead, leaving the universities wondering how they should adjust and keep their market share. It applies especially to Informatics. The effect makes the enrollment problem even more complex than it already is for each individual university in some countries, although the overall effect is likely to be beneficial for the field in general.

5 Informatics as Profession

... [an impediment to the introduction] of large scale computers into industry is the shortage of skilled problem analists and programmers. This difficulty has been

> *recognized and is being attacked from a number of angles both by schools and by the users of these machines.*
> R.F. Clippenger, B. Dimsdale, J.H. Levin (1955)

(Letizia Tanca)

The 1980s and 1990s have seen a steady increase of the number of job offers for computer technicians and programmers, either within huge projects for the production of large computer-based infrastructures (e.g. telephonic switches or electrical-power plants) or in the establishment of large-scale information systems. With the expected delay, applications for university courses in Informatics and Engineering have also increased. In this period, the Computer Science and Engineering studies were attractive mostly for mathematics-/scientific oriented students, who did not necessarily expect highly paid jobs, and who were content with the fact that their jobs were interesting and that job quest was very easy. Companies had a very high computer science personnel turn-over, and also salaries, even if not high, were quite dynamic. Things have changed and we will describe how. It has an effect on the view students have of the discipline.

5.1 The Quest for Jobs

In the 2000's, the focus of Computer Science and Engineering students has moved towards more applied and softer interests (e.g. internet-oriented professions) and, with the dot-com bubble, the salary expectations have grown along with the number of applications. Unfortunately this has not been associated with an equal increase in the student quality: as more, and better paid, jobs were expected, classes became more crowded, but not necessarily by students with adequate preparation or skills. The result is that the average 'product' of our faculties is less attractive than 20 years ago. As a consequence, companies do not expect that the newly-graduated job applicants from CS departments necessarily are high-quality students, and often do not offer attractive first-jobs.

The above analysis seems to be in contradiction with the following assertion:

> *Computing jobs are among the highest paid and have the highest job satisfaction. Computing is very often associated with innovation, and developments in computing tend to drive it.*
> Reason 4 from: Top 10 Reasons to Major in Computing (ACM).

but it is not. Indeed, the problem is rather the number of non-top graduates coming out of our schools. Computing people are very well paid, provided that they fulfil the expectations of the employers, who in fact are most willing to pay much and give satisfactory jobs to talented people who deserve them. Only, the job market is more competitive than 20 years ago, thus our task today is to produce better and more computer scientists and engineers.

Another reason for worry about the supposed decline in job offers and salaries is that many companies turn to cheaper labor overseas, the *outsourcing/off-shoring* phenomenon. Yet, as said in a January 2006 article on CNN.com, salaries for computing professionals (in the US) are rising extremely fast, and off-shoring is unlikely to halt this growth, for the simple reason that companies seek to maximize ROI rather than to minimize cost. Similar observations were also made by Jeremy Roche (CODA Group), Chairman of the European Software Association, in his relation "Challenges for the European Software Industry" at the first conference of the Informatics Europe association, in October 2006. Off-shoring means that software development is far from the companies headquarters, isolated and difficult to control. Strict control would be quite costly, thus companies will rather pay good software engineers at home than keep up the appropriate control structures overseas. Moreover, because of the enormous demand for people with strong IT and computing skills, the opportunities for software engineers and other information technology professionals are expanding in Asia, just as they are everywhere else.

Thus, even if overseas companies are asking for computer-skilled people, this does not correspond to a decrease of the job offers in Europe and the US; rather, it might be that the jobs offered in-country are more interesting than before, just because nowadays the less interesting jobs might be moved off-shore. The American Bureau of Labor Statistics (2007) also envisages that job prospects for graduates in the computing disciplines are expected to remain excellent throughout the next decade. And even if Europe is not the US, we don't see reasons why a similar prevision should not be made for Europe as well.

5.2 The Social/Personal Aspects of the Profession

Many students of other disciplines imagine computer scientists as narrowly focused lone wolves, sitting in a small workspace 'pounding out code 18 hours a day'. Contrary to what these students believe, computer scientists have interesting lives, friends, families and lots of social and cultural interests and hobbies.

> *Computing is often about being part of a team that requires people with many different kinds of skills. Yet there is also plenty of space for individual flair and imagination.*
> Reason 8 in: Top 10 Reasons to Major in Computing (ACM).

Aren't computing jobs solitary and boring? Actually, contrary to what many people think, computing professionals almost never work alone. Designing software products is not a one-person job, rather, a software project is an accomplishment of many people with a variety of skills. Designing a good product not only requires communication within the team, but also with the final users. Moreover, software analysis and development is also a very creative activity, since there is no way to mechanize a design process. Not all possess the extensive culture and open-mindedness that lead to rewarding achievements in such a creative task; accordingly, those who perform in with success, find a job in computing a most gratifying and challenging career.

One of the missions of university studies is to provide students with a broader view of their possibilities, including the opportunity to experience team work and to get acquainted with other disciplines, also because of the need to understand them as their application fields.

Insuring science and technology are considered in their social context may be the most important change that can be made in science teaching for all people, both male and female.
From: 'Female Friendly Science', Sue Rosser (1990).

5.3 Incubators

Many universities all around Europe offer various forms of 'incubator' facilities, that is, they offer infrastructures and shared secretaries to groups of young people who want to start up their own company. Examples are at Politecnico di Torino and at Politecnico di Milano, which in addition organizes, together with other universities in Milan, the STARTCUP contest. STARTCUP assigns two kinds of prizes: the former, for the Best Business Plan, encourages the presentation of innovative start-up projects on subjects within areas of competence of the research centers of the involved universities; the latter is the Call for Ideas, i.e. the collection of pioneering ideas, the most interesting among which will be fostered and incubated to produce a business plan for next years Business Plan Contest. The proposals should come from undergraduate, graduate or PhD students, young researchers, or even people outside the university world who want to collaborate with the university to start a novel business.

6 Informatics as Science

The current approaches to computer science education fail to teach the science of computing. As a result, they fail to inspire the very best and brightest young minds to enter the field. Computer science is faced with scientific challenges that rival any in history, yet are relevant to practical problems of today. Computer science involves questions that have the potential to change how we view the world.
J. Morris (2004)

(Jan van Leeuwen)

How to characterise Informatics as a science, or, to put it in a more thought-provoking manner: is Informatics a science (rather than 'just' engineering)? The question is a recurring one, as there is apparently no generally accepted answer yet. It is crucial for the 'image' of the discipline that the question be answered, as it is important for our (future) students to know that they (will) study a field of the same intellectual level and methodological rigor as any other scientific discipline - and some will add that the societal impact of Informatics is now the highest of all sciences. Answers are often based on particular individual perspectives: application-centric, computer-centric, computing-centric, curriculum-centric, engineering-centric, information processing-centric, methodology-centric, programming-centric, software-centric, technology-centric, AI-centric, and so on. Three classical examples are:

Computer science is the study of the phenomena surrounding computers.
A. Newell, A.J. Perlis, H.A. Simon (1967)

My favorite way to describe computer science is to say that it is the study of algorithms.
D.E. Knuth (1974)

... each of these [questions] is a special case of the general question, 'What can be automated'? and the answers will involve algorithms and their [..] implementation.
COSERS report (1980)

These are good working definitions for computer science but not satisfactory ones for the (broader) field if Informatics. They do not tell us whether Informatics is science (seen as the study of natural phenomena) or engineering (seen as the development and study of man-made artifacts) or perhaps both, and what the kernel as a science is. What are the truly fundamental questions Informatics is addressing in our eternal quest for understanding 'life', 'matter', or 'energy' and for mastering and recreating the world around us? In order to answer it we need a, still lacking, *philosophy of informatics.* Ultimately the question is of course: what does it teach prospective students, and will they care about it!? Most certainly they will, if they can relate to the answer and if it can bring a broader perspective than the continuing technological hypes do. It is a very important aspect of the whole image of the field.

6.1 The Information Dimension

The 'phenomena' that need to be understood in the effective use of (networked) computers and all other information processing media are so complex and extensive that this is now the field of highly skilled and specialized scientists. With the expanding views of what computers are or might be in the future, and the ever expanding range of applications in which (networked) computers and media are leading, computer science now is an extensive and fulfilling field of science of tremendous impact.

... informatics: the science of processing information through computer programs. At the heart of cell phones, airlines and airplanes, financial transactions, company management, publishing of any kind, the internet and world wide web, industrial plant control and all other devices and processes that make today's world run, lie algorithms and data structures devised by computer scientists.
From: 'Why study computer science' (ETH Zürich)

The computer-centric view does not quite capture the essence behind the phenomena that manifest themselves in Informatics. For the field of Informatics we need to delve deeper to find the deep motives that drive it as a science, making computer science a discipline with a broader scope of concern and placing it well within the domain of the Natural Sciences. It leads back to the views that were already expressed in the early days of computer science and that involve the deep appreciation of the concept of *information.*

Information ist der Urstoff des Universums.
A. Zeilinger (2005)

I consider computer science, in general, to be the art and science of representing and processing information and, in particular, processing information with [...] computers.
G.F. Forsythe (1967)

The ultimate purpose of physics is the intellectual one of understanding the physical world [...] Similarly we may expect that some day the agreed ultimate purpose of computer science will be to understand the behavior of information and the laws which govern its processing.
G.F. Forsythe (1967)

Computer science is concerned with information *in the same sense that physics is concerned with energy: it is devoted to the representation, storage, manipulation and presentation of information in an environment permitting automatic information systems.*
ACM Curriculum Committee on Computer Science (1965)

Here 'information' is appreciated as a crucial and foundational concept in understanding the physical, i.e. the natural or man-made world around us. Just like physical objects have mass and energy, they must admit to descriptions in suitable frameworks in the 'information dimension' to be fully captured and understood. This applies to everything, from 'real' biological systems (cells) to administrative systems up to the virtual constructs created by and in our imagination (virtual stores, games) and even our cognitive processes.

Everything that can be digital will be.
Razorfish (1995)

All processes, in nature or made by man, can be reduced to and modeled in a representation by, and the processing of, information.
J. van Leeuwen (2003)

6.2 Natural Science

The underlying inspiration is like in every science, that of bringing any 'world of interest' within the reach of understanding, in this case by means of models that will be made concrete as computer programs. Viewing 'models as programs' is the most powerful methodology of Informatics, now dissipating into all other field of science. And it is realized that information-systematic description and modelling is far more complex than (often partial) mathematical modeling, which often does not allow for the complete recreation or visualization of physical objects or their related phenomena. With programs as the ultimate models, many new aspects turn up that need understanding.

... algorithms are good at describing dynamic processes, while scientific formulas or equations are more suited to static phenomena. Increasingly, scientific research

seeks to understand dynamic processes, and computer science [...] is the systematic study of algorithms. Biology, Dr. Karp said, is now understood as an information science. And scientists seek to describe biological processes, like protein production, as algorithms. In other words, nature is computing, he said.
R.M. Karp, in: Stephen Lohr (2006)

The development of suitable (language-) frameworks for information system modeling with an eye towards the need of processing the information so captured was also conceived very early as an integral part of the information dimension.

... a central topic in the new discipline of computer and information science would be the synthesis and analysis of [mechanical] languages and their processors.
S. Gorn (1963)

There is thus no difference between physical objects and the virtual objects (constructs, systems) created in 'cyberspace' or in the human mind as normally envisaged in information modeling and processing. In all applied contexts, from biology to business, (approximate) informational description is the key challenge and a prerequisite for any further understanding of the real or virtual objects or any form of processing of these objects. With this view in mind, it is also clear that the science of Informatics has its origins well before the invention of computers and that, on the one hand, computers merely augmented the capabilities and thus the overall domain of challenging issues in Informatics; on the other hand, the need for appropriate formal modeling became clearer and more pressing as the range of possible computer science applications broadened.

The information sciences [read: informatics] deal(s) with the body of knowledge that relates to the structure, origination, transmission and transformation of information - in both naturally existing and artificial systems. This includes the investigation of information representation, as in the genetic code or in codes for efficient message transmission, and the study of information processing devices and techniques, such as computers and their programming languages.
G.F. Forsythe (1967)

Informatics is the study of the structure, behaviour, and interactions of natural and engineered computational systems.
School of Informatics, Univ of Edinburgh

The discipline of computing is the systematic study of algorithmic processes that describe and transform information: their theory, analysis, design, efficiency, implementation, and application. The fundamental question underlying all of computing is, "What can be (efficiently) automated?".
P.J. Denning et al. (1989)

Computer science [Informatics] is the science of information processes and their interactions with the world.
P.J. Denning (2005)

It is quite remarkable that the information-centric view originated already very early in the understanding of the field, with a far reaching and fundamental appreciation of the notion of information. With the dominance of computers and computer technology, this view seems have been pushed aside for quite some time, in favor of e.g. the computer- and programming-centric view of Informatics. Although these views have lead to a rich field of scientific endeavour, it is not clear that this 'restricted' view has been good for the general perception of Informatics. The current tendencies in the field seem to be correcting this towards a better balance, although this seems to be slow in penetrating the classical perceptions of the field. We note that the question whether Computer Science is rightfully a science, which it is, was already addressed and answered perfectly by Newell, Perlis, and Simon (1967) forty years ago.

6.3 Conclusion

It can be argued that one reason for the currently limited public profile of Informatics/Computing is the lack of a clear statement describing the discipline that is embraced by everyone in the field. Any such statement needs to be simple, chime with young people and the public, and convey the real importance and innovative nature of the discipline. The statement would have to highlight both the scientific and the technological sides of the field.

> *Informatics/Computing provides the science and the technology that underpins the development of today's digital world.*

This statement is broad but differentiates us fairly clearly from the ICT world. Note that the *digital world* includes, but is not restricted to, the virtual world. Within the digital world it is feasible (and often desirable) to model or simulate the physical, biological, material et cetera worlds and thus contribute to them. (The terms 'computing' as used in the UK and 'computer science' as used in the US seem less appropriate for it than the wider term 'Informatics'.) The view of Informatics/Computing as a natural science is also expanded by Denning (2007).

7 Image of the Discipline

(Jan van Leeuwen)

Given the enrollment problem and the challenge to attract good students, the question is whether prospective students and those who advise and influence them (friends, parents, teachers, universities) have the right view of Informatics as a scientific discipline. The crucial role for the enrollment problem is already expressed nicely in another very early observation. The following quote applies ipso facto for Informatics education as well.

> *Computer science education, like all education, must aim to inspire the student, rather than fill the student's store of knowledge. This education must create the field's leaders, and endow them with the ambition to attack the all-pervasive unsolved problems of computer science.*
> G.F. Forsythe (1967)

Indeed, it would not be an exaggeration to say that every significant technological innovation of the 21st century will require new software to make it happen.
Bill Gates (2007)

In the eyes of the prospective student, will Informatics be perceived as a field full of 'all-pervasive unsolved problems' that require great intellect, or as a field of 'all-pervasive technologies' that require mastering (and that are developed by unknown and invisible parties in industry)? The popular view of Informatics seems to lean very much towards the latter rather than the former, as opposed to the situation in other sciences like Physics. What is the reason behind this? Is it the fact that the technology-centric view is so dominant, or that the open problems in Informatics are not being articulated as well as in other fields, or is it something else? It may all be a matter of *image*.

Image: the opinion or concept of something that is held by the public and projected especially through the mass media.
Dictionaries

The image of Informatics seems to need far more attention than it has been getting. The image of a field determines whether it is deemed attractive or not. What makes the image of a field (in the eyes of prospective students), and what can we learn from it for the field of Informatics? The following aspects play a role.

7.1 The societal manifestation of the field

The dominant influence of Informatics and its resulting information and communication technologies is far reaching and this is already so for many years. No other science is influencing society now and in the future as much as Informatics, giving new meaning every day to terms like the 'knowledge society' and the 'information revolution'.

[Informatics] is changing the way we work, play, do business, spend money, and communicate. The computer is also subtly changing the way we think, communicate, and view the world.
J.E. Savage, S. Magidson, A.M. Stein (1986)

Advances in Computing change the way we live, the way we work, the way we learn, the way we communicate .... Computer science is a field of incredible intellectual opportunity.
E. Lazowska (2006)

Especially by the development of inter-networks, culminating in the Internet and the World Wide Web since the early 1990s, the changes go fast and are no longer subtle. We are all connected, work and live in smart environments that will suit our needs better and better, and everything around us gets 'informatised'. New communities and businesses are formed every day due to the creative tools of Informatics. Society is being reshaped by IT and this requires great insights in new usable systems concepts and designs. It is a powerful factor for the science of Informatics, almost unparalleled by other sciences.

7.2 The economic manifestation of the field

> *Den Nutzen der Tätigkeit betonen.*
> A. Endres (2007)

The 'information revolution' is reflected by the enormous economic impact of the information service industries. Companies like Amazon, Google, Microsoft, Oracle, SAP, Yahoo and many others are pushing the field daily for new visions, new ideas, new concepts, new theories of multimedia information processing, new applications, and new products. Many small(er) companies create similar challenges and seek the best of ideas that come from the top Institutes in Informatics (and their own research labs) for exploitation in their markets. ICT now is the biggest factor in industrial and business process innovation. The creative challenges this poses for the field are gigantic and need to be expressed more as driving forces in research (to students as well as to research institutes).

7.3 The technological manifestation of the field

The technologies resulting from Informatics have opened great possibilities for scientists and non-scientists alike. Computing is recognized as an indispensable partner to scientific discovery and technological development and is becoming the 'Crown Princess' of Science. In core fields like Computational Systems (from algorithmics to cluster computing), Multimedia (from graphics engines to visualization methods), Information Retrieval (from massive data stores to search tools), Cognitive Systems (from sensor networks to intelligent systems), and Information Systems (from information modeling to supply-chain informatisation), informaticians are increasingly probing into every imaginable corner of science, industry, business and society to discover the full informational foundations, and pushing for new information technologies. It is often not well exposed to students that the results and achievements in applications are (based on) achievements of deep research and conceptualizations in computer science.

> *One thing computer science is not: it is not merely the the union of the applications of a computer to diverse problems. Rather, the core of the field is application-independent and rather abstract, being concerned with languages and techniques that are relevant to a variety of different applications of computing, in much the same way that mathematics is an abstract tool that is relevant in many different applications.*
> G.F. Forsythe (1967)

7.4 The scientific manifestation of the field

It appears to be far less easy to point at the great achievements of Informatics as a science, in terms that are easy to appreciate for young students and which are not fitting under the 'technological' header. There is almost no tradition to name and propagate great findings as true 'discoveries' of the field. Results are often partial and presented as 'we proved' or 'we built' and hardly as 'we discovered'. There is nothing wrong here with Informatics except that its science image seems widely underrated. Consequently it is hard to use this image convincingly to prospective students, without positioning Informatics also as a *discovering science* to a much greater extent. Possibly this view leads us into the 'information dimension' of the field again, which is by definition a multidisciplinary dimension like in any other science. This was realized from the very beginning in Informatics although the computing-centric view easily suppresses this perhaps as an inalienable part of Computer Science.

> *. . . The study of programming is the the study of communication between man and machine. The general trend of programming research is in the direction of simplification of this communication, at the same time making the fullest possible use of computer potentialities.*
> R.F. Clippenger, B. Dimsdale, J.H. Levin (1955)

> *The [computer] scientist often views the computing system as a means of extending the natural intellectual capacities of man. He may theorize on the information processing that people [or natural systems] engage in to obtain abstract systems which are intended to complement man's own processing capabilities.*
> Keenan (1964)

> *However, because of the newness of the field, computer scientists must now be concerned with the applications of computer methods in many different areas of technology and learning [...] computer scientists engage in a very broad spectrum of activity, ranging, for example, from pure logic to communication engineering, from the psychology of learning to business administration, from computer analysis of the content of documents to medical data processing, and from pure mathematical analysis to methods of plausible inference about the accuracy of experimental algorithms. [...] Because of this broad sweep of activity, the nature of computer science is usually misunderstood and deprecated by those with its acquaintance, however close, to only one aspect of computing.*
> G.F. Forsythe (1967)

Not surprisingly the computing-centric view has been so dominant over the years that the position as a multidisciplinary science has almost slipped away. It is important that we refresh the scope, and thus the image, of Informatics as a science.

> *. . . computer science must reach out much more to other disciplines, from psychology, philosophy, sociology and linguistics to medicine, biotechnology, nanotechnology and beyond, because the computational metaphor is now at the intellectual core of most disciplines.*
> Y. Wilks (2007)

Gradually departments are following suit as shown in the following inspiring example.

- *Systems covers all aspects of the building of both hardware and software computational systems.*

- *Perception and Learning includes work on the sorts of things that all people manage to do effortlessly, both emulating those abilities, and simulating their appearance.*
- *Physical, Biological and Social Systems might also be called complex adaptive systems, and cover work from robotics, to molecular biology, to semantic systems, to computational models of politics.*
- *Theory looks at the fundamental mathematical underpinnings of all aspects of computer science and artificial intelligence.*

From: CSAIL mission, MIT.

7.5 The community manifestation of the field

Über berufliche Erfolge reden.
A. Endres (2007)

Finally, the 'communities' that are active in all branches of Informatics are a decisive factor for its image as well. This varies from the visibility and activity of a student union that 'binds' students together, to a good view of the many professionals who work in the field, in industry, in business or in the 'science of informatics'. Students tend to know everything about leading industrials like Steve Jobs and Bill Gates but very little if anything about the leading people in Informatics research and their successes (such as the Turing Award winners). More should be done to restore this, not only for students but also in the public media. The image of Informatics as a science is not complete without a clear image of the professional (scientific) community and its scientific leaders, so that students can identify with it more and feel that they want to be part of this community.

8 Ideas and Discoveries in Informatics

The computer is the science lab of the future.

(Jan van Leeuwen)

Exploiting the rich domain of Informatics as a science for the benefit of the enrollment problem is non-trivial. For many (prospective) students 'societal relevance' is more important than 'scientific relevance', i.e. the practical context and applicability of the research appeals to them more. Science is seen as important but students often wonder what it relates to and what it leads to. From this perspective it does not pay to emphasize the science aspect of Informatics too abstractly but it is better to reach one's goal indirectly by showing (possible applications of) concrete research projects. The best, and often easiest, way to interest students for the great ideas, discoveries and inventions in Informatics is to use examples from research projects in one's own department. If the curriculum is organized such that already early on in the bachelor studies students get close to or can even participate in research duties, then this is a very effective way to 'grab' and inspire them for the science of Informatics.

8.1 Fundamental Issues

Yet, pushing on, what do we answer (or tell) students when they want to know what the great issues are in Informatics? What are the truly fundamental questions Informatics is addressing in our eternal quest for understanding man and the world around us. What fundamental insights have arisen that have surprised everyone? Is there a body of knowledge of varying degrees of certainty. Are there theories to test? Are there experiments aimed at validating theories or insights? Are there answers that convince?

At an abstract level, Informatics seeks to find the limits of *modelling*, *programmability*, *usability*, and resource-bounded *computation*, and tries to push these limits as far as possible by both structural research and technological development. Informatics addresses, for example, the quest for:

- *suitable models*: of the Internet, of social networks, or organizations, of the cell, of the brain,...
- *efficiency*: P-NC, P-NP, NP-RP, large data sets, online computation, limits to what can be computed within given resource bounds, ...
- *computing principles*: physical assumptions that make hard problems easy, quantum computing, process modeling, interaction, ...
- *programming principles*: objectization, generic programming, transformation, virtualization, coordination, communication, ...
- *effective systems*: information systems, services, grasping user needs, usability, scalability, productivity paradox, business IT alignment, ...
- *simulated intelligence*: knowledge representation, agentization, learning, system adaptation and evolution, robustness to component failure, ...
- *information infrastructures*: self-regulating ad-hoc networks, value chains, global information spaces, web 3.0, ...
- *supertheories*: the ultimate programming framework, autonomic programming, new ways of doing things (in research or anything), ...
- *laws of information processing.*

> *Three of the truly fundamental questions of Science are: "What is matter?", "What is life?" and "What is mind?". The physical and biological sciences concern the first two. The [emerging] science of Informatics contributes to our understanding of the latter two by providing a basis for the study of organisation and process in biological and cognitive systems. Progress can best be made by means of strong links with the existing disciplines devoted to particular aspects of these questions.*
> Quoted from: School of Informatics, Edinburgh.

8.2 Discoveries

The next hard question is what the *discoveries* in Informatics are. (Actually, there is nowadays a field called Discovery Informatics and this is obviously not what we mean here, although it is an interesting case in point of what Informatics leads to. Discovery informatics is 'the study of computer and mathematical techniques that get useful information from large streams or collections of data, the science of getting new ideas from existing information'.)

> To discover:
>
> - *to obtain sight or knowledge (of what was not known) for the first time, to bring to light something previously unknown,*
> - *to find out what one did not previously know (applied to something requiring exploration or investigation),*
> - *to find something that had previously existed but had hitherto been unknown,*
> - *to determine the existence, presence, or fact of,*
> - *to be the first, or the first of one's group or kind, to find, learn of, or observe.*
>
> To invent:
>
> - *to make or create something new, esp. something ingeniously devised to perform mechanical operations,*
> - *to produce (as something useful) for the first time through the use of the imagination or of ingenious thinking and experiment.*
>
> Dictionaries.

Here very much depends on one's interpretation and appreciation of the (many) fundamental results in Informatics. A *sample* of results that may count as discoveries, exciting results or great technological achievements is listed below, for the purpose of inspiration. Each example comes with a world of history and scientific achievement that makes for great stories in Informatics culture and that can be the source of great *demonstrators*.

> Exciting discoveries (examples):
>
> - *Von Neumann architecture*
> - *Client-server model*
> - *Hypertext*
> - *Levels of translation of computer languages*
> - *Computer can be used for human-to-human communication*
> - *Web can be used as a PC*
> - *Definition of [classical] computability*
> - *Core of intractable problems*
> - *Formal frameworks for problem mapping/solving: calculi, LP, CP,..*
> - *Public-key cryptography*
> - *Randomness as a computational resource*
> - *Formalization of reasoning about code*
> - *Anthropomorphic/cognitive modeling of systems through 'autonomous agents'*
> - *Distributed systems can self-organize*
> - *Massive data spaces can be searched effectively*

- *Structure of spontaneous/social networks*
- *Virtual-world models*
- *Embedding and digital simulation of complex physical phenomena*
- *DNA can compute*
- *Principles of quantum computing*
- *Everything can be digitized.*

Exciting results (examples):

- *Undecidability of the halting problem*
- *Chomsky hierarchy*
- *FFT*
- *Quicksort*
- *Strassen matrix multiplication*
- *Cook-Levin theorem on NP-completeness*
- *P vs NP cannot be solved by techniques that relativize*
- *Linear-time pattern matching*
- *Linear Programming is in P*
- *Euclidean TSP has a PTAS*
- *PRIMES are in P*
- *The PCP theorem*
- *RSA scheme for public-key cryptography*
- *Polynomial time factoring on quantum computer model (Shor)*
- *Damas-Hindley-Milner type inference*
- *Lazy evaluation of functional programming languages*
- *OOP*
- *MPEG/JPEG/...*
- *Kolmogorov complexity-based similarity measures*
- *Deep Blue beats Kasparov*
- *Business processes can be outsourced/offshored.*

Exciting inventions (examples):

- the microchip and many other hardware inventions
- list of the *most important software innovations* (cf. Wheeler)
- list of the *most important algorithms* (cf. Koutschan).

Exciting achievements in systems (examples):

- *Aloha network*
- *Programming languages of choice*
- *Multics timesharing system*
- *IBM PC*
- *Tablet PC*
- *Windows*
- *Unix/LinuX*
- *TeX*

- *Spreadsheets*
- *Office systems (MS Office, OpenOffice)*
- *Glasgow Haskell Compiler*
- *IP and VOIP*
- *World Wide Web*
- *Web browser*
- *Open GL, DirectX, RenderMan*
- *Advanced games (graphics engines and world modeling)*
- *Physics engines (Havok engine)*
- *iPod*
- *Computer graphics in movies*
- *Data/image compression*
- *XML/RSS*
- *Mobile ad-hoc systems*
- *Workflow and CSCW systems*
- *ERP systems (SAP, Oracle, PeopleSoft, ...)*
- *BLAST*
- *Molecular computers (nanomachines)*
- *Service-oriented architecture.*

8.3 Developments in Informatics

If discoveries are of the recent and not so recent past, the question for students (and ourselves) arises: what remains to be discovered, what great developments are foreseen in the science of Informatics? Generally, ICT is seen as a 'disruptive' technology but this applies very much to the technology- and application-centric view. Where are the scientific developments going. Again the question is best answered for students by taking examples to which they can relate and that are within grasp by the things they learn in the curriculum or in the research groups in your department. Here is a typical example (not quite designed for our present argument but good enough as indication):

> *Informatics, although a young science, already covers a wide array of interconnected specialties. Here are some of the topics that you will encounter in your studies at ETH:*
>
> - Programming and software engineering*: how to write high-quality programs, from small to extensive, that will fulfill the needs of their users.*
> - Theory*: the mathematical basis for computation and programming.*
> - Algorithms and data structures*: finding the most efficient and elegant techniques for solving computing problems using the smallest possible time and space.*
> - Compilers and operating systems*: the engineering tools that support the efficient use and programming of computers.*
> - Networking, distributed systems, the internet, the web*: connecting the entire world.*
> - Graphics, multimedia, human-computer interaction*: making the experience of using computers pleasant and effective.*
> - Real-time, embedded systems, pervasive computing*: enabling devices of all kinds, from cars and home appliances to factories and space rockets, with the power of software.*

- Security, privacy, cryptography*: protecting users of computers and software-equipped devices from attempts at malicious use.*
- Information systems and databases*: organizing the often enormous amounts of data that programs need to process.*
- Scientific computing*: serving the ever growing needs of large computations in science, engineering and finance.*
- *And many other topics... some just emerging.*

From: website Dept of Computer Science, ETH Zürich.

From a higher viewpoint one likes more visionary images of the driving questions of the field. What future developments can be projected within the scope of the science? This brings us back to the needed philosophy of Informatics. Here are some examples of trends and developments driven by scientific research and technology push.

Great trends (examples):

- *Multiple-core machines*
- *Computational and wireless grids*
- *Content-centric networking*
- *IPv6, Web 3.0*
- *Embedded technologies*
- *Ambient intelligence/smart surroundings*
- *Supply-chain informatisation*
- *New emerging transaction models*
- *Service-oriented computing*
- *Human-centered computing*
- *Creating digital experiences*
- *Enhancing the capability of human creative thinking*
- *Trust models in information security*
- *Global computing*
- *Quantum information science*
- *Man-made brain.*

However, the most exciting development is that Informatics/Computing is now reaching far beyond its core domains and penetrating deeply into the sciences. Simultaneously it is influencing and changing the face of many other fields. This is seen everywhere around us and documented in a compelling way e.g. in the *Towards 2020 Science* report from 2006. The report argues convincingly that Informatics/Computing is now integrating into *the fabric of science* and that many new developments in science will in fact be occurring at the 'intersection of computer science and the [other] sciences'.

> *Computing changes what can be seen, simulated and done. So in science, computing makes it possible to simulate climate change and unravel the human genome. In business, low-cost computing, the Internet and digital communications are transforming the global economy. In culture, the artifacts of computing include the iPod, YouTube and computer-animated movies.*
> Stephen Lohr (2006)

The new social-and-technology networks that can be studied include e-mail patterns, buying recommendations on commercial Web sites like Amazon, messages and postings on community sites like MySpace and Facebook, and the diffusion of news, opinions, fads, urban myths, products and services over the Internet. Why do some online communities thrive, while others decline and perish? What forces or characteristics determine success? Can they be captured in a computing algorithm? Social networking research promises a rich trove for marketers and politicians, as well as sociologists, economists, anthropologists, psychologists and educators. "This is the introduction of computing and algorithmic processes into the social sciences in a big way [...] and were just at the beginning.
J. Kleinberg, quoted in: Stephen Lohr (2006)

Conceptual and technological tools developed within computer science are, for the first time, starting to have wide-ranging applications outside the subject in which they originated, especially in sciences investigating complex systems, most notably in biology and chemistry.
Towards 2020 Science (Microsoft Research, 2006).

Informatics changes every science that it touches. This leads the way to many promising new directions in research.

The important task of bringing these developments out into the open and speculating about them, in particular about those developments *not* directly tied to hard- and software products, needs far more attention than it has been getting in the past. Without it there can be no adequate public perception of computer science as a science.

8.4 Grand Challenges

At a grander scale, in some countries, there are efforts to 'push' research developments in (certain branches of) Informatics by posing *grand challenges*. All challenges relate to the 'quests' we formulated earlier but give them a concrete focus, e.g. on the development of ubiquitous (omnipresent) computing systems. For detailed information on the grand challenges listed below we refer to the relevant websites. Each challenge problem is a domain full of excellent theoretical, experimental and technical problems that are inspired by the 'vision' of the challenge. The process of identifying grand challenges that hold promise of truly pushing ICT science and technology ahead is intriguing.

Grand challenges (UKCRC):

- *In vivo - in silico: the virtual worm, weed and bug*
- *Science for global ubiquitous computing*
- *Scalable ubiquitous computing systems*
- *Memories for life: managing information over a human lifetime*
- *The architecture of brain and mind*
- *Dependable systems evolution*
- *Non-classical approaches to computation*

- *Learning for life.*

Grand challenges (CRA):

- *Systems you can count on*
- *A teacher for every learner*
- *911.net (ubiquitous information systems)*
- *Augmented cognition*
- *Conquering complexity.*

Grand challenges II (CRA)

- *Eliminate epidemic attacks ('by computer') by 2014*
- *Enable trusted systems for [...] societal applications*
- *Accurate risk analysis for cybersecurity*
- *Secure the ubiquitous computing*
- *environments of the future.*

The science of Informatics is also intimately tied to the great visions in technology. These visions are often linked very closely to projected advances in (the understanding of) information processing modes, highly distributed systems, programs and the technology on which all these things can be realized. The 'science-technology-user spiral' is turning out new challenges every day in this process. Here are a number of powerful speculations. Many of them seem 'self-fulfilling' for Informatics.

Great speculations (examples)

- *Gigantic programs will self-maintain*
- *Wireless microchips will hook everything to the Internet*
- *Human-centered design will allow us to make software reliable and dependable*
- *Moore's law will continue indefinitely, in media other than silicon*
- *Quantum computers will render all current methods of cryptography obsolete*
- *Information will be accepted as the basic principle of biology*
- *Ubiquitous computers will promote energy conservation and make green living become fashionable*
- *Armies of robots will explore outer space, planet earth, and the interiors of our bodies*
- *Sensor-driven implants and bionic body parts will significantly extend lifespan*
- *All man-made things around us think and connect.*

Cf. P.J. Denning (2001)

An outstanding list of speculations for future information technologies (until 2050) is also contained in the *BT Technology Timeline.*

8.5 Discussion

Informatics has many facets: professional, societal, economic, technological, and scientific. The latter is the hardest of all to exploit in the efforts to let students appreciate that Informatics is a challenging field up to par with any other science.

> *Apparently, unlike mathematicians or astronomers, computer scientists can pursue certain lines of research only if somebody else considers them useful.*
> S. Santini (2006)

Yet the science view urgently needs to be addressed, as Informaticians and Computer Scientists are expected to follow suit on the great insights that developed in the *science of Informatics* over the years. IT now drives the advances in many other sciences and this isn't only because of the smart use of advanced information technology but very much also because of the dedicated investment of great scientific research in Informatics along the classical 'information dimension'. Many computer science departments (and their scientific staffs) clearly have invested heavily in the technology-centered view of Informatics in the past and are only slowly expanding their scope now. It is often felt as a forced drive towards application domains but it is to be appreciated more intrinsically as a drive towards the broader classically intended scope of Informatics ('the information dimension'). The development is a fundamental one as it will focus Informatics again on the deep understanding of information processes in the natural and artificial world, instead of on the tools for exploring it *only*.

The utilitarian views of computing are still abound, often neglecting that all new technological ideas need advanced research and development efforts before they come into being. In the popular image of Informatics there is often confusion between 'computer use' and 'computer science'. It can even lead to the view that computer science consists of 'what students need to learn that was invented in the computer industry'.

> *I think it's important to understand that, of all the computer programming disciplines, enabling people to browse, search and otherwise use structured information on the Web is among the easiest to teach and learn. The languages, protocols, models and many of the components are well-established. It really isn't rocket science.*
> J. Small, posted on Oct 3, 2006

Rather the opposite is the case. Informatics has advanced deeply in all its facets, its tools are now as advanced as in any other science (to the extent that they are greatly wanted by the other sciences), and slowly but surely the prerequisites are fulfilled to let broader science aims of Informatics emerge again. The question is whether students (and faculty members) feel the same way and are motivated by this development, which could impact considerably on the field. The science image of Informatics as it exists may still be too underrated, compared to the technological image.

9 Conclusions

(Jan van Leeuwen/Karl Posch)

A stereotypical view of Computer Science students is that they like 'computers' but not 'science'. This view has passed and should no longer be kept alive: the enrollment problem is one reason for it, but also the trend in Informatics shows that the field develops very rapidly into the *science of information (systems)* that it always was, with all its multidisciplinary aspects. This does not mean that the technology-oriented view is becoming obsolete, on the contrary. It rather means that a greater balance is needed with the other aspects of Informatics, viz. with Informatics as science.

9.1 Informatics and the Next Generation

Many, if not most professional informaticians in their 50s and older are immigrants into computer science themselves. They have moved into this field most likely because they were fascinated by the possibilities of what you can do with computers. They were fascinated by the sheer unlimited options these machines could be used for. Virtually all of these professionals saw how computers became a commodity, and how a worldwide network was built out of this commodity. Also the revolution of wireless communication with miniaturized computers as personal nodes belongs to this phenomenon.

But for today's and tomorrow's kids and young adults, mobile communication and the World-Wide Web have always been. It is just boring. Or, at least, they do not feel the hype around it in a way older professionals perceive it. Moreover, they have probably spent a huge proportion of their lifetime in front of this thing, be it a gaming station, a mobile phone, an MP3-player, or anything the like. And they have not felt that knowing more about these commodity things might help them to become 'a hero'.

In order to approach the next generation of young adults and thus our future students, we need to have better methods of communicating the fascination of inventing a new world where everything is (or has) a computer (inside) and may communicate with its environment. And for proper approaches we might have to do two things: Make them understand that solving future problems will usually involve computer science as a basic methodology. And give them an idea of how many worlds can be invented based on this methodology. Let them dream up a world where computers have no size, cost nothing, are able to communicate with their environment, and get their energy from the ambient energy around. Finally, help them to understand today's technology (appropriate to their age) so that they get a feeling for tomorrow's possibilities. These ingredients – foundations, visions, and hands-on experience – should be applied in the right proportions.

9.2 Informatics as Academic Discipline

If prospective students and their advisors (parents, teachers, student deans) are to have an adequate impression of Informatics as a science, then we need an adequate *philosophy of Informatics* that expresses clearly what its scope and long term aims as a grand science are. This can inspire the bright students we need to enter our fascinating field of study and join the dynamic departments to study and later, businesses, industries and research laboratories to help develop Informatics further. The image of Informatics as a science needs much more attention in this respect than it is getting (within Informatics).

Yet one should not overrate students in their appreciation of 'pure science' and this holds especially for future Informatics students. The image of Informatics is still strongest in the technological direction for them and they may rather be scared by anything that tells them that Computer Science may not be what they think it is. But we need to propagate

Informatics explicitly as a field for people who 'think' about the properties and structures of the information world we live in and join in discovering how this world can be mastered. Early exposure to ongoing research in the department is a much needed component of the bachelor curriculum in order to stimulate the scientific curiosity of students and to let them appreciate the challenges of research. The same holds for prospective students, who often like the information about their field of study to be as concrete as possible.

> *The College of Computing is expanding the minds and horizons of students here on campus and around the world. We understand not everyone wants to be a programmer and that computing is an essential component of nearly any industry a student would want to work in. Our unconventional approach to education is pioneering the new era of computing and allows you to gain the most appropriate computing knowledge for the future endeavors YOU want to pursue.*
> From: website College of Computing, Georgia Tech.

> *Strong research groups exist in areas of artificial intelligence, robotics, foundations of computer science, scientific computing and systems. Basic work in computer science is the main research goal of these groups, but there is also a strong emphasis on interdisciplinary research and on applications that stimulate basic research. Fields in which interdisciplinary work has been undertaken include chemistry, genetics, linguistics, physics, medicine and various areas of engineering, construction, and manufacturing. Close ties are maintained with researchers with computational interests in other university departments. In addition, both faculty and students commonly work with investigators at nearby research or industrial institutions. The main educational goal is to prepare students for research and teaching careers either in universities or in industry.*
> From: website Computer Science Dept, Stanford University.

9.3 Recommendations

> *To prepare their graduates for tomorrow's IT world, CS departments should consider implementing the following measures:*
>
> - *Offer multidisciplinary and cross-disciplinary programs*
> - *Fix computing science's image*
> - *Increase women's enrollment in CS*
> - *Train high school computing science teachers*
> - *Make CS courses fun.*
>
> Q.H. Mahmoud (2005), L. Carter (2006).

The enrollment problem of any discipline quickly leads to the essential question of describing and characterising the nature of the discipline as perceived in science and in society, and especially in the minds of young people. This is no different for the discipline of Informatics. It can be noted that there seems to be no clear 'philosophy of Informatics' as yet and even a consensus on the fundamental existential questions of the field is not always clear. Yet, under the fitting name of the 'Information Revolution' the vast developments in Informatics over the past decades are consistently and deeply impacting on all activities in society and continue, leading to a world view in which computers, internet, the Web, and digital media are only the tools of discovery for a future that builds on them. For prospective students we need to be clear on the motives of the field, even though their own tangible goals stay with the technology only. They should feel part of the 'higher aspirational goals' of the field and we must make clear what they are. Thus, for every department there is all reason to invest more in the proper image of Informatics, at any level:

- the field,
- the Bachelor curricula that are offered,
- the Master programs,
- the professions,
- the research programs,
- the department,
- the scientific staff, and
- the image the scientific staff gives of the above.

Nevertheless, the enrollment problem is not only a matter of 'images'. Informatics students must be able to think logically, critically and creatively. Algorithmic thinking and problem solving is part of the day-to-day routine of Informatics and flexibility in thinking is a necessary component of success. Employers recognize these traits in Informatics graduates and find these qualities desirable. Are we attracting these students in sufficient numbers? And do students buy into our vision that their future should be in Informatics?

The enrollment problem requires a joint, consistent effort of (European) scientists and (European) industry to open up the field and its beautiful domain of work, to show that it is a field of people instead of computers, and that it is socially a field of status. This effort should subsequently lead to effective challenges that appeal to young students and motivate them for the deeper studies in the Bachelor and Master programmes and perhaps in the longer run, for PhD-studies or research in industrial laboratories to contribute to the intellectual advancement of the Informatics field.

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