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Between the disciplines

Computer Science as a discipline has come of age. In fact, as a human worker it could face retirement. CS is one of the few new disciplines that evolved and grew, searching and finding its place between other disciplines – mathematics, electronic design, economy, and others. By its origin it was an interdisciplinary challenge. And this challenge still exists. New fields of applications emerge, while the basic foundations are still in question. Is CS really a "Very Large Application of Logic," as Edsger Dijkstra once summarized, or is it shifting towards one of the fashionable media studies, or should it evolve to a serious engineering practice as David Parnas points out? There seems to be a long winding road before us – but there is neither a "dead-end road" nor a "giant leap" in sight. Quite certain, CS will reposition under the influences of new application like digital media and the demands of other disciplines from genetics and nano-technology to marketing a.k.a. "customer relationship management." What is new for CS compared, let's say, to literature, chemistry, or astronomy? Probably, it is the steady flow of new connections to other fields whether as application areas or as deeper connections as in bioinformatics, digital media, or computational linguistics, where CS does neither stand as fixed body of rules and methods, nor as a well-defined field of objects to be investigated.

In a certain way, CS is a new discipline that did not evolve from a distinct and clearly defined demand. Even the name reflects this problem. Computer engineering and computer programming are a wonderful technological challenge but is difficult to interpret that as a science in a traditional understanding. The continental European usage of the artificial word "Informatik", or "informatique" is not much better. CS was a tentative approach to educate a new class of high level technicians bitterly sought by industry and administration. The answer was a more or less contingent construction from the sources available, i.e. the pioneers of electronics, numerical mathematics, or business data processing, ready to join the universities as teachers and researchers. In the next CS was open to many disciplines from semiconductor physics, psychology, statistics, business administration, or even applied design. This interdisciplinary approach was simply necessary, because the problems evolved, e.g. to interactive use of terminals ("human computer interaction"), in self-adapting pattern recognition ("artificial intelligence"), or to distributed computing (from grid computing to "artificial life"). Inter-disciplinary research is probably in the very core of CS. But did we really recognize that? Do we prepare are students for such a demanding task? I am afraid we do not. But we should do.

The formal division of disciplines seems to be of little value for our field (and many other too). But then: Why are there different disciplines in science? What is their value? The traditional answer is that disciplines have different areas of interest ("objects"), and different approaches to deal with these objects ("methods"). (You may also add "classes" to become more familiar). Throughout centuries higher education followed several aims, among them:

• Acquiring thorough competencies in certain fields
• Acquiring knowledge,

and last not least

• Acquiring status

Members of the clergy as well as the secretaries and officials of the state were introduced and prepared by higher studies. To some extent the sons and in rare exceptions even the daughters of the upper classes (there they are!) were educated in these institutions. The medieval schools were founded in antique system of education, separating the trivium and the quatrivium, to achieve the basic aptitudes, namely Grammar, Logic, and Rhetoric.
Those three disciplines were considered to be basic, or trivial - hence trivium. In addition, the quatrivium formed the liberal, or practical arts – at least at a time where the ruling classes were not as ignorant of cultural activities as in later times: Arithmetic, Geometry, Astronomy, and Music.
This of course is the Pythagorean curriculum, by which not only Plato was educated, but also Aristotle and Alexander the Great, and nearly any ancient Greek and Roman pupil. But these practical or "liberal" arts were only the lower faculty in medieval universities – unchanged until the days of the enlightenment. The higher faculties were practical in an advanced sense – they defined the knowledgeable part of the ruling élite, namely *Theology, Medicine,* and *Law*.

In Germany it was Immanuel Kant who first attacked that established order of knowledge. Kant tried to define science strictly in the spirit of the enlightenment to be founded on logical truth. As a logical consequence he denounced the higher faculties to be basically non-scientific because they were not founded on scientific truth. Theology is based on the bible, the law is based on the arbitrary rules and books of law, and medicine is based on a tradition of healing and the books of medicine, but only vaguely on the knowledge and investigation of the human body. This, of course, was Kant's view, I must hasten to add ;-)

In his bold attack ›*Der Streit der Fakultäten* (The struggle of faculties)‹ written in 1794, at a time when the French revolution was the main event in all European discussions, Kant places philosophy (which also took over liberal arts at his time) in front of theology, law, and medicine – because it was based on the search for truth. Of course, that was a truth within the limits of human potentials, which were so brilliantly analyzed by the philosopher himself, quite different from any transcendental truth, unachievable for the human reason.

But Kant was in no way a theoretician and philosopher, floating above the practical sciences. He was rector of the Königsberg university in East Prussia and a teaching professor. By the way, it may be inspiring what Kant considered to be read by a university teacher in philosophy. His interests are far apart from the disciplinary modesty that governs our modern highly specialized faculties. Kant taught courses from 1724 to 1804 in

- Logic (4 hours per week, 54 times)
- Metaphysics (4 hours per week, 49 times)
- Ethics or Practical Philosophy (28 times)

Beyond these philosophical basics he taught

- Mathematics (4 hours per week, 12 times)
- Theoretical Physics (20 times)
- Physical Geography (3 hours per week 46 times)

In addition Kant twice taught *Mechanics* (4 hours per week), *Natural Law* (4 hours per week, 12 times), *Philosophy as a Survey* (4 hours per week, 12 times), *Anthropology* (4 hours per week, 24 times), *Natural Religion or Philosophical Foundations of Religion* (4 hours per week, 2 or 3 times), *Pedagogics* (2 hours per week, 4 times). It seems that he liked *Mineralogy* to a lesser degree, because he taught it only once. In addition to his lectures he offered exercises for his philosophical courses. Kant was not the only professor with such an extensive programme of lectures, as the disciplinary borders of modern science were not so firm, was but he may also be considered as an eminent example of the humanistic renaissance tradition – a universally interested researcher and teacher.

It was Wilhelm v. Humboldt who defined, shortly after Kant died, a new university structure thought to be appropriate for the post-revolutionary Europe. 1806 he proposed to the King of Prussia a modernized university structure, while the country was still occupied by Napoleonean troops. While Wilhelm v. Humboldt's thinking was deeply rooted in an education with classical languages as fundamental orientation it should be kept in mind that his university reform was also a reaction on the deepening gap of universities and academies. Contrary to the expansion of academies as research units, Wilhelm v. Humboldt postulated *a unity of research and teaching*. He also postulated the guideline ›Einsamkeit und Freiheit‹ (*Loneliness and Freedom*) for university teachers – obviously under the influence of the French adversary and quite an *affront* against his own king, Friedrich Wilhelm I, but also a warning that science should not be too close to politics. Humboldt responded also to Napoleonic reforms that created Grandes Écoles for the recruitment of Administrators and Army Engineers – still in clear contrast to the French universities. While Napoleon wanted a new technically knowledgeable élite, Wilhelm v. Humboldt referred to humanistic heritage and tried to rejoin a tradition lost.

The organization of the new Humboldtian university was modern, but its contents ignored the already belated dawn of the industrial revolution in Germany as well as the demands of the Prussian army. "Those, who come too late, will be punished by life." Humboldt's classical turn was of short duration. His influence on the Berlin University was thwarted before the new university opened its doors, and the university allowed Natural Sciences and even Technology (in the Physics department).

The rapid progress of research but also the rapid economic development in the following years induced as large variety of disciplinary splits in university teaching. This was grossly enforced with the advent of commercial schools (*Gewerbeschulen*) for the newly formed technical elite. These were transformed in a keen battle to Technical Schools at university level at the end of the 19th century with the privilege of doctoral studies - in fact by direct imperial degree of the Kaiser, but it was only in the last decades of the twentieth century that these Schools were named what they already were for nearly a century - Technical Universities.

The diversification of disciplines was sometimes accelerated not only by broader views on scientific objects, but also by methodological considerations. A striking example is Wilhelm Dilthey's separation of *Geisteswissenschaften* and *Naturwissenschaften* (humanities vs. natural sciences) with which he forced a split in psychology research. The philosopher and psychologist Dilthey was one of the successors of the great physicist Hermann v. Helmholtz, and his adversity against the natural sciences may be understood as an attempt to declare his independence from a tradition founded by Helmholtz. In fact, Helmholtz' research was influential not only in physics, where he formulated mathematically sound *the principle of conservation of energy* and also *the fundamental theorem of kinematics*, but also in psychology where he investigated color sensitivity as well as musical sensations or in medicine, his first field of study, where he invented to ophthalmoscope, an eye mirror still in use nowadays. But the disciplinary split that Dilthey and his coworkers postulated along the relative position to human history was effective beyond psychology - to an extent we may consider from our perspective to be disastrous. It is interesting to observe how a field like Computer Science that started so deeply rooted in technical design has to find nowadays so many bridges to non-technical fields of application.

In this short exposé of the development of sciences we saw that strict disciplinary splits are a relatively new development (once we learn to think in centuries instead of semester terms) and that some of these splits are not very well founded. But they exist, and now we have to learn construct bridges between the disciplines. We may call that *transdisciplinary* work, as the word interdisciplinary implies an equivalence between different disciplines that only few may achieve.

In a way the fragmentation of research and education into a large number of disciplines mirrors the division of labor in an industrial society. While the division of labor may be steered by the desire for higher productivity (as elaborated already by Adam Smith), it should be noted that the organization of industrial labor is founded in the examples and experiences of cloisters and military. Factory work from the early manufacturing processes to the assembly lines of Henry Ford and to process chains in the chemical and petrochemical units is deeply rooted in this heritage. Meanwhile we experience a shift from *Fordism* to a post-industrial society where teamwork, assembly groups, or service providers become dominant industrial structures. After the complete division of labor up to the "scientific management" of Frederick W. Taylor, we experience now the demand for highly competent but rather flexible workers. It is beyond doubt that even university education is under the pressure to deliver graduates that are flexible beyond the disciplines, and demonstrate social skills that allow them cooperate in teams of quite different members – and lead them if appropriate. But there seems to be no interdisciplinary work without a disciplinary foundation. It cannot be ignored that technological progress is founded on deep insights with narrow perspectives. High-level research in the natural sciences and in technology demonstrated its innovative power with this type of research. But it is also evident that this enormous specialization led also to disciplinary ignorance and that it reduced the usefulness to knowledge from a lifetime to a few years. As an immediate consequence the necessity for life-long education is a result of highly specialized research. CS started as small communities but nowadays it is also split into branches that do rarely cooperate even if it is obvious that such cooperation will be very rewarding. Think of the useful integration of compiler technology and processor architecture as it was demonstrated with RISC-technology (a cooperation that needs some refresh as far as I see).

But modern production demands not only highly specialized researchers: there is a growing demand for a more constructive attitude where "generalists" are able to re-assemble the fragments of high-level research transforming these results into product and services or even product and service lines. Thomas Alva Edison "invention factory" is an early example of combination of focused and specialized research with the ability to recombine such research in product development, but today's computer industry (lead for decades by companies like IBM) is a perfect example of such developments. As many modern product lines or services have restricted life cycles, it becomes obvious that their management must be coordinated with a highly flexible attitude. Life-long learning becomes therefore a strict demand – sometimes as learning by doing but more and more as the challenge of advanced training and continued education. This is clearly a process of fragmented education, dispersed over the whole lifetime. No longer can we rely on the traditional sequence of school-university-job. This sequence will loose its character of the standard type of education. Training on the job is not sufficient in highly complex fields of academically trained labor; more and more short sequences of training and productive work will define a job. As a simple consequence of such an insight school and university studies can no longer constitute a complete education. Then these phases have to shortened and the institutions have to be opened for on-going education processes – unless this high level education is delegated to other institutions.

In fact, we already have experiences with such structures though they are still not dominant. Distance learning studies like the British Open University exist, and support some of these demands of on-going education or university training. Some universities offer supplementary add-on studies, but this is of restricted value if these are added to a traditional curriculum – it makes much more sense if it is considered as training after sufficient job experiences. Our universitities are not really open to such an idea.

Another answer would accept the fact that many students especially in informatics and IT-related fields are actually working in these fields during their university studies. The curriculum must reflect and accept the existence of part-time students – and support them much mire than it is actually done. Part-time studies are another example of fragmentation of education.

Unavoidably this means also a stronger inclusion of practical experiences into the curricula - either as an underlying assumption, namely that students are already practicing their field of studies to some degree or as an explicit part of the university studies.

Of course self-studies are a simpler answer to the growing demand of adult training, but they show also distinct disadvantages. Sometimes the idea of Internet based distance learning is propagated for a revised form of self-studies. It seems to be too early to judge the practicability, but there are promising field studies.

Education will become a life-long endeavor; we should not expect that the sequence of education blocks follows traditional curricula as they were mandatory in disciplines. A successful life-long learning process must assemble different pieces of curricula from different disciplines. So, it is not difficult to foresee that law and economics or management courses will become standard elements in the learning process for engineers or computer scientists. Contrary many trained in social or cultural sciences will include elements from computer science into their life long curriculum. This cannot be without influence on the disciplines as they are formed now. New disciplines may arise (like e.g. chemical engineering, media informatics, or media economics) but this will not be the final answer. After some period of adaptation, we will become accustomed to complex mixes of different disciplines, which will be based in these different disciplines. Computer Science may be in the core of these processes. The actual question is not to ignore disciplinary boundaries with its methodological differences but to open the disciplines for collaborative work. We must learn to build bridges, not to start in the gap between disciplines.

CONSIDER THIS TO BE AN OPPORTUNITY!