Chapter 3
On Informatics, Diamonds and T

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Abstract This chapter reflects upon Information and Communication Technologies (ICT, including informatics) research and education in the light of current technology trends. My key messages are that (1) ICT has become ubiquitous and therefore runs a risk of becoming understated and worse, underappreciated. (2) because of its widespread use ICT is evolving to be more involved in interdisciplinary research. I argue that interdisciplinarity itself is inherently a team effort, requiring an individual to consider team-work in a fundamentally different way. The conclusion which emerges from the previous statements is that researchers and engineers in ICT should be better prepared for working in interdisciplinary teams and understand that continuous, deliberate effort is required for successful team building.

In this chapter, robotics is given as an example of interdisciplinary research area, heavily relying on ICT expertise but also progressively on far interdisciplinarity (e.g. with biology, social sciences, law, etc.). Using the metaphor of T-shaped competences, a possible profile of an expert in this field is described and as a case-study, the development of Centre for Biorobotics, is analysed. I conclude with some personal experiences from working in and building interdisciplinary teams.

3.1 Setting the Scene

Current technology trends foreshadow the rapid advances in technologies, where informatics (or more generally ICT, information and communication technologies) play a leading or important role. Amongst them are the rapid development of mobile internet, knowledge automation, cloud services, as well as the Internet of Things and advanced robotics (Manyika et al. 2013). The amount of data created every day is increasing with a progressing rate and will reach nearly 45 ZB by 2020, according to Oracle's 2012 forecast. Managing this rapidly growing volume of data

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needs new theories and new methods as well as allowing for new approaches to be rapidly applied.

Another rising trend is the emergence of physical and virtual worlds, in the so-called Internet of Things, where smart sensors and devices are connected to the Internet. Gartner, Inc. forecasts that 4.9 billion connected devices will be in use in 2015, up 30% from 2014, and will reach 25 billion by 2020. This would support total services spending of $69.5 billion in 2015 and $263 billion by 2020.

Robotics is another growing domain where ICT plays a major role. The growth in robotics is mainly expected to happen because of robots moving from its traditional application domain in industry into the service sector. In particular the amount of privately used service robots (such as vacuum cleaners or lawn mowers) is expected to increase most but also the service robots for professional use (for example for military use, in agriculture and transportation) is steadily increasing. It is estimated that by 2018 the total robotics market will reach 100 billion dollars whereas the service robots are behind 85% of this growth (IFR 2015). As a characteristic example we are witnessing today the arrival of consumer drones that are now available in every tech store at affordable prices. Their market share has risen from USD250 million to USD1800 million in 2 years (2013–2015) (Meeker 2014).

3.1.1 Robotics as an Interdisciplinary Area Involving ICT

The situation of ICT development bears a resemblance with the Water and Diamonds value paradox. If asked, everyone would first answer that diamonds are more valuable that water because diamonds are rare and precious but water is present everywhere and is cheap. However, one can very well live without diamonds but not without water. In that sense water is much more precious (ISTAG 2010–2012). ICT seems to be such a substance, diluted and embedded in almost every object and service, so that one ceases to appreciate its importance and starts taking it for granted. At the same time, in modern world it is almost impossible to survive without it. As such, ICT in one hand is highly in demand but most of all in its applied form. On the other hand, for a discipline to develop and advance, one needs highly specialized research to push the research frontier forward. Of course, it can be argued that the balance between applied research and development and basic research should be found in every discipline but the argument in this chapter is that ICT more than other disciplines runs a risk of getting diluted.

Robotics is a good example of an interdisciplinary research area that is heavily dependent on computer science and computer engineering. Even if we are used to thinking of robots as mechanical machines, most of the methods, skills knowledge and expertise in robotics is computer science and computer engineering related (Eu Robotics 2014).

Classically, a robot is a mechanical machine, which is electrically controlled, whereas the control is implemented on digital computers and may also include (and nowadays usually does) high level planning and decision-making affordances. Thus classical robotics already is an interdisciplinary field comprised of mechanical engineering, electrical engineering, control engineering, computer engineering and computer science. Here expertise of close disciplines (e.g. mechanical and electrical engineering) or specialties within the same discipline are emerged (e.g. electrical engineering and computer engineering).

The above-described emerging trend of consumer robotics is pushed by and pulls specific research areas in informatics and other disciplines so that robots would be able to reliably function in real world environments. Whereas traditionally industrial robots where working in almost static well-defined industrial environments on pre-programmed specific tasks (e.g. point welding in car industry), consumer robots work and interact with humans in their natural environments which are dynamic and on tasks that vary. This in turn requires a number of new functionalities. The robot now perceives the world around it with a variety of sensors. The sensor information has to be processed, analysed and perhaps fused together with information from different kinds of sensors (sensor fusion). Information from other different sources (e.g. online databases, other robots) can be used to detected the changes in the environment and interact with it. Then the robot has to make plans and take decision under circumstances where data is often noisy and almost always incomplete. Finally, if these robots are connected to the internet and receive or upload information to the cloud, they become part of the Internet of Things. As such, robots can be viewed as mobile data collecting machines.

On the research front, modern roboticists also work on paradigm shifting robotics technologies that could possibly provide entirely new kinds of ways for designing robots. Among those is for example material science, where roboticists hope to find new ways of building robots from e.g. lightweight, soft and sometimes active materials. Also bio-robotics is a rapidly emerging research trend which seeks to apply principles of biological systems developed by evolution in robot design. This may involve new types of bio-inspired locomotion, bio-inspired sensors or sensing principles as well as new ideas to build reliable control methods based on analogy with neurocircuitry of animals. In addition, many ideas of cognitive science are entering robotics and form a so-called subspecialty of cognitive robotics. Cooperation with developmental psychologists provides ideas how to build self developing and learning robots. The whole subfield of human robot interaction heavily relies on cooperation with social sciences in order to develop most efficient methods for interacting and cooperating with the robot as well as predicting how humans would adapt those kinds of new technologies.

The above given examples of advanced robotics are examples of far interdiciplinarity where engineering disciplines and computer scientists cooperate with biologists, material- and social scientists.

Moreover, moving closer to our everyday world robotics is faced for the first time with Ethical, Legal and Societal (ELS) issues. Would people accept a robot taking care of their children or elderly, who will be responsible if a surgical robot damages a patient or what happens to people who's jobs will disappear because of the rise of robots. These are just a few examples of a myriad of problems that roboticists, traditionally been educated as engineers, seriously face for the first time.

3.1.2 Specialty Profiles and Interdisciplinary Research

The challenge facing ICT research and education is thus how to keep a balance between increasingly widespread demand of applied research and engineering while still maintaining sufficient depth to push the frontiers of its field. Obviously, there is no interdisciplinarity without disciplinarity. Therefore this chapter argues that interdisciplinarity should preferably be achieved on the level of a team rather than of the individual. A suitable metaphor, originally used in business management, for describing a preferable width and depth ratio is the concept of T-shaped profile (Hansen and Von Oetinger 2001).

This competence building paradigm has also made it to the academic world and has been considered as a desirable outcome of university education (Rip 2004; Uhlenbrook and Jong 2012; Heinemann 2009). And certainly, this approach lends itself easily to various interpretations. A skills profile that someone considers as vertical, may occur flat, without sufficient depth and therefore mainly horizontal for another. However, I suggest that T-shape profile is still a valuable metaphor in order to assess, envision and plan the competence development.

Essentially, the T-shaped profile means that a person (or on a system level, an organization, team, etc.), has a strong specialization in one specific area, comprising the vertical bar of letter T. The horizontal bar then is comprised of various skills that are acquired rather superficially but let the person to easily interact with another person with a different competence. Depending on interpretation, the horizontal bar may include communication skills, creative thinking, team-working skills, project management skills etc. Science and technology development seem to need progressively more individuals competent in ELS Issues. The horizontal bar can also comprise knowledge in other scientific and engineering disciplines (e.g. statistics, biology, arts, etc.) but the main idea is that the extent of those skills is not comparable with the competence in the vertical bar. I have found a good indicator that the vertical is in place if the person can answer: "*I am an expert in ....*". If the person cannot name his/her area of expertise or names several, the knowledge is not T-shaped.

Such a T-shaped competence profile suggests that the interdisciplinarity is reached not on the level of a person but by a team of professionals. Comprising an interdisciplinary team then becomes quite obvious, the team is glued together by matching horizontal bars of team-working skills and secondary expertise whereas every individual remains responsible for providing deep knowledge in his or her area of expertise.

Of course such a shape of a T can describe the competence on the level of an organization. Some examples are a company with a core competence to make it competitive in a global market niche (Nordström et al. 2000), a research team specializing in a narrow area of research, an university curriculum with a goal to educate experts in a certain area. The challenge again becomes to identify its core expertise and to maintain horizontal competences for cooperation on more challenging interdisciplinary tasks.

Certainly, this is a dynamic challenge, expertise can be developed and changed and indeed, should change in response of the changes in the environment (market needs, job availabilities, technology trends and developments in science). From the perspective of the individual it becomes important to match the individual competences to the needs of the environment. One can bring an analogy with an evolution of biological systems. If the environment is very stable, species can afford becoming more specialized and maximizing its likelihood of survival in a narrow range of possible conditions. On the other hand, if the environment is unstable, generalists tend to do better. The technology forecast in the opening section of this chapter offers some insight into the specialization areas that add most value in the future.

3.2 Shaping Centre for Biorobotics: A Case Study

This subsection gives an overview of the development of Centre for Biorobotics in Tallinn University of Technology, Estonia which I founded in 2008 and discusses the challenge of building a team through the rough-hewn prism of personal experience. As the name of the research centre indicates, it already focuses on interdisciplinary research however, as it becomes evident by the end of this section, even interdisciplinary teams benefit from specialization and focus.

Biorobotics, being a subfield of biomimetics (or bionics) is a research area that discovers and uses principles from natural systems to create physical models, and engineering systems. Biomimetic and bioinspired robots include for example flying robots inspired by insect flight (Floreano et al. 2009), terrestrial robots using principles of snake locomotion (Transeth et al. 2009), sensors and sensor information processing methods inspired by bat echolocation (Peremans et al. 2000), or other so far overlooked sensor modalities such as active touch (Prescott et al. 2011) or flow sensing (Salumäe and Kruusmaa 2013). It may also be motivated by working principles of neural circuitry to achieve reliable control (Ijspeert et al. 2007). As it can be seen, the variety of possible research themes is so wide that for a small research team (10–20) people some further specialization is absolutely necessary.

Furthermore, the funding opportunities for research in Estonia are limited and highly competitive. While in European countries in general about 50% of funding is project based, in Estonia the competitive project based funding constitutes about 80% or more of research funding and is in most of cases highly competitive. That situation in turn sets limits to the size of the research team, been basically determined by the ability of the principal investigator (PI) and other senior staff to attract funding. Therefore, further specialization was necessary to achieve the competence in some area that is able to deliver cutting edge research results.

Table 3.1 Competence profile of Centre for Biorobotics

Year	Research competences	Supporting engineering skills	Collaborations (far field interdiciplinarity)
2008	Mobile robotics, robot learning, Smart materials, underwater robots	Electronic engineering, computer engineering, computer science	Material scientists
2009	Mobile robotics, active textiles, underwater robots, underwater sensing, smart materials	Electronic engineering, computer engineering, computer science, underwater engineering, sensor technique, mechatronics	Applied arts, material scientists
2010	Mobile robotics, active textiles, underwater robotics, underwater sensing, soft body modeling, soft robotics	Electronic engineering, computer engineering, computer science, underwater engineering, sensor technique, mechatronics	Fish biologists, radiologists, surgeons
2011	Underwater robotics, flow sensing, soft body modeling, active textiles, soft robotics, flow sensing, medical imaging	Electronic engineering, computer engineering, computer science, underwater engineering, sensor technique, mechatronics	Fish biologists, radiologists, surgeons
2012	Underwater robotics, active textiles, flow sensing, soft robotics, experimental fluid dynamics, medical imaging	Electronic engineering, computer engineering, computer science, underwater engineering, sensor technique, mechatronics	Fish biologists, radiologists, surgeons, underwater archaeologists
2013	Underwater robotics, flow sensing, soft robotics, experimental fluid dynamics	Electronic engineering, computer engineering, computer science, underwater engineering, sensor technique, medical imaging mechatronics	Underwater archaeologists, fish biologists, hydraulic engineers, control engineers
2014	Underwater robotics, flow sensing, soft robotics, experimental fluid dynamics, ecohydraulics, hydraulics	Electronic engineering, computer engineering, computer science, underwater engineering, sensor technique, mechatronics	Fish biologists, hydraulic engineers, Oceanographers, optical engineers, control engineers
2015	Underwater robotics, flow sensing, soft robotics, experimental fluid dynamics, ecohydraulics, hydraulics	Electronic engineering, computer engineering, computer science, underwater engineering, sensor technique, mechatronics	Underwater archaeologists, fish biologists, hydraulic engineers, oceanographers, optical engineers

Table 3.1 summarizes the changing focus of the research group since its establishment in 2008. All the areas listed in the "research competences" have lead to at last one Ph.D. thesis from the lab. The starting years reflect the uncertainty of the strategic goals, but also uncertainty about funding possibilities and preferences and previous areas of research of the PI and its members. Various possibilities are considered, and every funding opportunity is used. Over the years, the focus of the

group gets more and more narrow, converging around underwater robotics, and underwater engineering.

Underwater robotics, and underwater engineering in general, are one of the areas of technology that are more than average costly and time consuming, involving much of so called "invisible work", mostly technical work for keeping devices watertight that by itself are not a subject of research but still requires highly skilled support engineers and technicians. Fluid dynamics experiments in terms of test tanks, special measuring and flow visualization equipment require certified personnel. Field-testing is another activity that, been dependent on weather, cost and availability of vessels, and other environmental and human factors, requires specific knowledge, skills and equipment. Learning here happens to a great extent by trial and error and over a long time period. It is therefore natural that, after getting over the entry barrier, one would decide to leverage on the accumulated knowledge and skills that also becomes a strategic asset of the team. Good results in turn lead to more research opportunities and new interesting collaboration in new but similar topics.

Besides the support engineering skills it should be pointed out that the team of Centre for Biorobotics also comprises one assistant to the manager who is responsible for all the administrative and financial matters, including EU project administration.

The last column of Table 3.1 lists our main collaborators. To be observed here is that over the years, also more computer engineering competence gets outsourced. It turned out to be more efficient to keep our narrow and unique competence and instead, collaborate with other individuals and groups that are distinguished experts in their field. The first outsourcing questions we asked ourselves in the beginning was if Centre for Biorobotics should develop expertise in both of the involved disciplines, biology and robotics. After flirting for a short while with the idea of hiring fish biologists, building facilities for animal housing and acquiring licenses for animal experiments we rather quickly decided that for the resources available its more feasible to cooperate with already established experts in this field. Retrospectively, this appears to be a very feasible decision. In a similar vein (Nordström et al. 2000), argues for what they call "hollow companies" in business management. Those companies would outsource everything but their core competences and be competitive in a relatively narrow, but a global niche.

3.3 Lessons Learned

Globally, interdisciplinarity is on the rise. Since 1980, research papers have increasingly cited work outside their own discipline (Van Noorden 2015). I suggest that because of global technology trends, IT research will be more widespread and part of almost every new technology and technical solution thus increasingly interdisciplinary. Obviously there is no interdisciplinarity without disciplinarity. But because of the extent of research and application areas an ICT expert would need extra training and show readiness to work in interdisciplinary teams, while still maintaining their T-shaped competences.

Mainly based on personal experiences, I am in favor for interdisciplinarity on a team level, rather than on a personal level. It has proven over the years that most interesting, fruitful and mutually beneficial collaborations happen between experts in different fields with good team-working and interpersonal skills. Deepening your own specific competence while staying serendipitous and open to new viewpoints has the potential to tackle new interesting problems.

Below are listed the most important personal lessons I have learned by trial and error (and mostly error) from leading and participating in international and interdisciplinary teams:

- **Find a common goal**. The common goal should be something that is related to the general problem statement and goes beyond what is considered as an achievement in a specific field of science or engineering. For example, I found computer scientists and computer engineers in medical engineering finding a common goal in improving patient care, contradictory to the wide misconception of that "computer nerds" don't care of those things. In another project, BONUS FISHVIEW, where we study water flow in fishpasses using signal and image analysis, novel sensors and computer simulations we first defined a naïve-sounding goal of "making fish happy". However, everybody in the team found they easily relate to it and the concern about environment would make them better work together. In my opinion writing good publications is not the best common goal because they are on different topics in every field and every researcher has personal interest to publish in their favorite journals. Rather a publication could be viewed as a formalization of results, while the result is something more general. Especially when working with companies, who are not concerned about publishing but making profit, this goal is not motivating.
- **Search until you find right (T-shaped) people**. Communication problems in interdisciplinary teams are quite common, especially if the common goal is lacking. As a consequence, everybody pulls in his/her own direction (perhaps publish her own papers). Not all good experts obviously are good team workers. It makes sense to put some effort in finding a good person for interdisciplinary work instead of later struggling to make people work on a common goal they are not interested in.
- **Listen**. It takes time and willingness from all team members to understand the interests and personal goals of others as well as some understanding what methods, equipment and other resources they have. Usually people are quite willing to talk about their work, the tricky part is listening and finding overlaps and complementarities. Not understanding what methods, equipment and technical approaches others are using often leads to bad planning and missed opportunities to solve really significant problems.
- **Accept that interdisciplinary work takes more time**. Defining a common goal, finding right type of people, understanding the way the business is done in other areas, establishing common vocabulary, common work routines and

communication channels take more time if people come from diverse backgrounds. For unusual combinations of interdisciplinary work there is often no standard test equipment, no commonly accepted methods and even agreement over what can be considered as a result. All those things need to get established before the project delivers. Therefore some more ramp-up time is necessary to be planned in interdisciplinary projects.

– **Respect the standards and culture in other disciplines**. Different disciplines differ not only because of their methods, problem definitions and technical approaches but also by their working culture, ways of communication, and what is considered to be result or success. It is also not entirely unusual that we underestimate the effort other groups and people put into solving a common task because we are not entirely familiar with their work procedure and cannot fairly estimate their contribution. It is worthwhile spending time on building a common culture that everybody agrees on.

In Brown et al. (2015) authors give a complementary but rather similar list of recommendations for building interdisciplinary teams. It differs by more general recommendations on shaping adequate financial, institutional and policy instruments to support interdisciplinary work.

3.4 Summary and Conclusions

This chapter gives a brief overview of current technology trends and investigates one of the emerging technologies, advanced robotics, as an example. It argues that informatics and other information and communication technologies will be the core part of almost every emerging technology megatrend. Therefore there is a risk for ICT research and engineering to get diluted because of value paradox (it is not given sufficient value because it is ever-present, hidden and often taken for granted). Because of its wide applicability this risk is larger than in other disciplines and the challenge to find balance between broad and wide expertise, theory and applications is more severe. T-shaped competences are discussed as a metaphor for educating experts able to cooperate over a great variety of domains whereas it is argued that the T-shape is favorable both on the level of an individual as well as of an organization (research team, company, etc.). It described as a case study a short history of establishing and developing Centre for Biorobotics in Tallinn University of Technology, Estonia and finally gives some personal experience-based recommendations for creating and working in interdisciplinary projects.

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