Sport Informatics – Historical Roots, Interdisciplinarity and Future Developments

Daniel Link & Martin Lames

Munich University of Technology, Faculty of Sport Science

Abstract

Computer science has become an important partner for sport science. Although many cases for the successful application of computers in sport exist, only a few meta-theoretical mediations on this research field can be found. To fill this gap, this paper looks at the genesis of sport informatics in Germany, discusses the interdisciplinary relation between computer science and sport science and forecasts its development up to the year 2020. Using existing models of interdisciplinarity the paper classifies research activities into four types of cooperation and emphasizes the importance of "genuine" interdisciplinary research. This discussion leads to a compact definition of sport informatics and to a graphical model, which illustrates its subject matter and the structural relations between sport science, computer science and their fields of application. The future section identifies increased computing power and network capacity, networks concepts such as pervasive or cloud computing, small one way electronics, flexible displays and positioning technologies being the most relevant technological improvements for sport. These technologies have a potential impact e.g. on the measurement and reporting of physiological and positional data, on computerized performance analysis, sport clothing and the quality of computer simulations in the fields of sports engineering, motor behavior and physiological adaptation.

SPORT INFORMATICS, THEORY OF SCIENCE, DEVELOPMENT, DEFINITION, FORECAST

Introduction

Over the past three decades, the discipline "sport informatics"[1] - also called "computer science in sports" - has become an important part in the spectrum of sport scientific research. The term covers all activities at the interface of computer science and sport science, ranging from simple tools for handling data and controlling sensors on to the modelling and simulation of complex sport-related phenomena. Whereas first applications in the 1970s used computers for information and documentation purposes only, current approaches describe virtual environments for the training of perception tasks specific to sport (Levy & Katz, 2007), the scope of computer technologies for coaching (Lames, 2008) or the automatic analysis of sport games using pattern recognition (Hoyningen-Huene & Beetz, 2009).

[1] The term sport informatics originates from a congress in Graz (Austria), organized by the International Organisation for Sports Information (IOSI) in 1975. The related proceedings were published by Recla & Timmer (1976) under the German title "Kreative Sportinformatik" (engl. "Creative Sport Informatics").

Today, computer science in sport is a well-established research field. An International Association on Computer Science in Sport (IACSS) has existed since 2002 and promotes research in this area. In many countries such as Australia, Croatia, Germany, Turkey and India national workgroups have been established, which represent sport informatics in the national scientific community and contribute new technological innovations to sport. The IACSS also maintain good relations with various other sport scientific organisations like the International Association for Sports Information (IASI), the International Council of Sport Science and Physical Education (ICSSPE) or the International Sports Engineering Association (ISEA).

Although there is no lack in research activities and scientific institutionalization, only a few meta-theoretical studies on sport informatics can be found. Most publications reports on applications of computer technology, software tools and informatic methods and paradigms in sport, but they do not deal with epistemological questions about the discipline. While some authors (Perl & Lames, 1995; Baca, 2006) suggest a rough internal structure of the discipline, others (Fischer, 1998) allude to the characteristics of interdisciplinary cooperation, but forgo a detailed discussion.

This situation prompted the authors of this paper to reflect from the point of view of sport informatics on the development of the discipline, to analyse its current situation and to speculate on its future. As the foundation of the IACSS was preceded by several national working groups, the first section of this paper will give a brief overview on developments in Germany and intends to make the German perspective available to readers outside of this country. The second section discusses the interdisciplinary relation between computer science and sport science and identifies different types of cooperation. Based on this discussion section three suggests a definition and a structural model of the discipline. The fourth issue is extrapolation: we know of some possible developments in informatics, but what will be their impact on sport mediated by sport informatics? This question is addressed in the last section, where we propose ten short theses about the state of the discipline in 2020.

Historical Roots – The Development in Germany

The discussion about interdisciplinarity in sport informatics should take into account the concepts of the individual disciplines. The first two subsections outlines the conceptual structure and conception computer science and sport science have of themselves and focuses on the epistemological discussion in the German scientific community. The third subsection gives a short overview about the institutional development of sport informatics in Germany.

Computer Science

In the sixties and the seventies of the last century, in Germany the term "Informatik" was mainly associated with questions of technology. A popular German encyclopaedia described "Informatik" as "the science of the systematic processing of information, in particular the automatic processing using digital computers" (Engesser, 1986). In terms of this definition, the discipline includes mathematical activities, which deal with algorithmic processes for the description and transformation of information and also engineering activities, concerning aspects of the development and application of computers. This technological perspective conforms to the common understanding of the discipline "computer science" in the United States or Great Britain (National Research Council, 2004).

In the beginning of the eighties, the importance of computer systems increased in almost every part of society. It became more and more clear, that the use of computer systems leads to interactions between system processes and the processes in the real world. To study these interactions, many computer scientists adopted approaches and methods from social and behavioural sciences. These research fields were accepted as a part of the discipline "Informatik". Today, many countries use the English term "informatics" - derived from the German "Informatik" - for the science of information. Nygaard (1986) for example defines "informatics" as the "science that has as its domain information processes and related phenomena in artifacts, society and nature". This perspective separates the mathematical/logical part from the technical one and refers to the concepts of cybernetics and system theory.

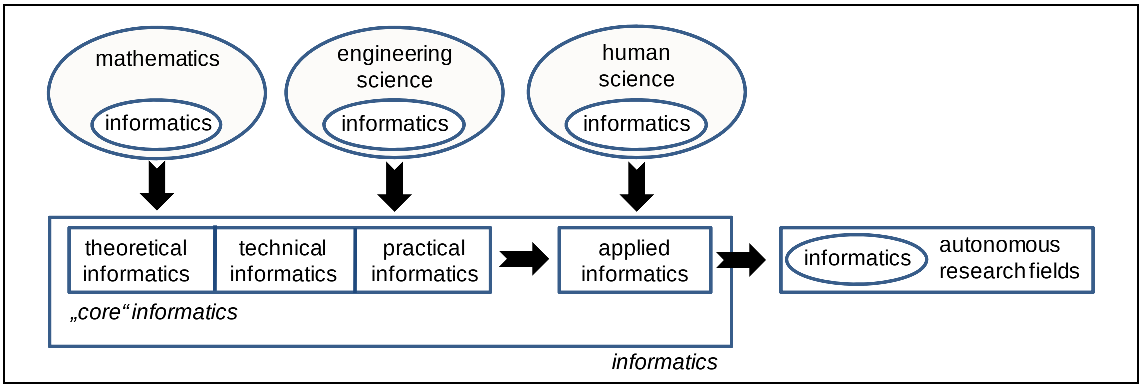

Fig. 1. Commonly used structural model of informatics. Informatics emerges by separation from mathematics and engineering science - later approaches from human sciences were integrated. The discipline is divided into the subdisciplines theoretical, technical and practical informatics, which are called "core"-informatics (Claus, 1975). The application and question related to the use of computers are studied by applied informatics. Also some autonomous research fields like bio-informatics or neuro-informatics exists, but they are not treated as a part of the discipline.

One characteristic of computer science is its ambition to support others scientific disciplines. In many cases the combination of technical expertise from computer science and specific domain knowledge leads to autonomous research fields like bio-informatics, neuro-informatics, business informatics or sport informatics. In Germany there was a debate about whether these research fields should be accepted as a part of the discipline. Luft (1992) for example, claims a strict distinction between the cooperation fields and the core area of "Informatik". Today, the discipline in Germany (also "Informatique" in France) is a kind of mixture between computer sciences and Nygaards concept of informatics (see Fig. 1), but nevertheless the question about its boundaries is still a topic of discussion.

Sport Science

German sport science has undertaken a definition process akin to that in Informatik. One common definition, published in a German Sport Encyclopaedia, describes sport science as the "collectivity of knowledge, scientific argumentation and research methods that deal with problems and phenomena related to sport" (Röthig & Prohl, 2003). While this definition is obvious, it provides no sight into the epistemological characteristics of the discipline. For example, it is quite difficult to define, what the term “sport” exactly means. One approach was the formulation of criteria, which are common to all instances of sport (e.g. motor activity, principle of organisation, non-productiveness, fair-play, performance). It is easy to see, that these criteria - however they are selected – do not apply every type of sport. To call an activity sport, it is neither necessary that all criteria are present, nor is it possible to say, which of the possible combinations can be regarded as being sport.

Another important point in the theoretical discussion is the relationship between the subdisciplines of sport science. In the late 1960s, the existence of German sport science was contentious. The proponents needed a good reason as to why a new discipline with its own structures and resources should be established in the academic landscape. Therefore the argument was put forward that the complexity of sport could not be investigated by existing research fields (Grupe, 1971). The exigency of one unified discipline, with a high degree of interdisciplinarity between its subdisciplines, was the central argument for the foundation of sport science. To support this position, Ries and Kriesi (1974) proposed a model, which shows the development of sport science in three phases, (1) detaching from base disciplines, (2) aggregation of subdisciplines within a multidisciplinary science and (3) integration of sub disciplines into a consistent and integrative science (Fig. 2).

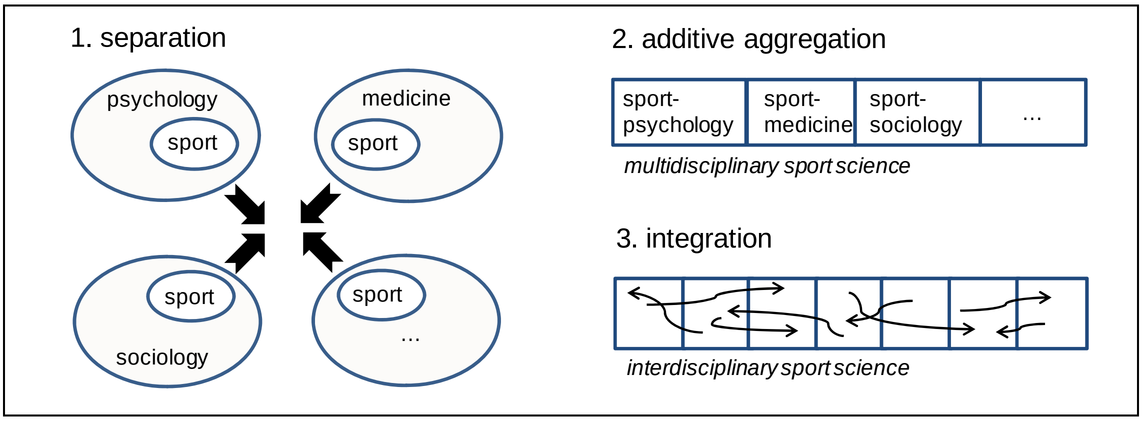

Fig. 2. Idealized model of sport science development (Ries & Kriesi, 1974). Detaching of sport related research fields from bases sciences, additive aggregation into a multidisciplinary science and integration of sub disciplines into a unified science.

The scientific reality showed, that - in contrast to this idealized model - sport was mostly studied through the eyes of each subdiscipline (e.g. sport sociology, sport psychology, exercise science). Today, German sport science has accepted that the idea of an integrative science was not a very realistic one. Sport science does not describe itself as a “unified science of sport”, but as a collection of overlapping research programs, in which interdisciplinarity exists only in a sporadic and theme centred way (Höner, 2001).

Sport Informatics

The idea of an interdisciplinary science “sport informatics“ in Germany was developed initially by Jürgen Perl. Together with Wolf Miethling he published the first monograph in the discipline (Miehtling & Perl, 1981) and marked the beginning of sport informatics in the Federal Republic of Germany.

Since 1985, Jürgen Perl has worked at Mainz University and founded a working group in sport informatics. Contacts with other German groups in this field of study led to workshops on sports and informatics. The first of these took place in Hochheim in April 1989. It was attended by the most important German sport science groups in this subject. This first workshop was supported by the German Institute of Sport Science indicating the strategic importance attached to this development. It was the starting point of a series of biannual conferences. The most recent workshop (the 11th German Workshop on Sport and Informatics) took place at Augsburg, Bavaria, in May 2008.

In 1994 a new strategic aim was pursued. The German Association of Sport Science (Deutsche Vereinigung für Sportwissenschaft (DVS)) represents German academic sport science with 900 members at 67 universities. It is organized in sections, representing the disciplines of sport science, and commissions giving an organizational framework for special interdisciplinary topics, like health or gender, but also for single sports like football and swimming. The strategic aim of establishing a section within DVS dedicated to research activities in the field of sport informatics possessed many attractive perspectives. First, the responsibility of caring for the research area would not be solely the task of the Mainz working group. Other groups were interested in organising the workshops. Second, being under the umbrella of DVS meant that there is much more support for example, to organise conferences, and improve access to the community of sport scientists from all other disciplines. The most important point though was establishing a section in DVS meant that sport informatics was acknowledged a discipline of sport science in Germany.

In September 1995, the general assembly of DVS supported with overwhelming majority the request to establish the Sport Informatics Section. This may be considered the formal birth date of the scientific discipline. This vote was, of course, the final act of a chain of political actions and personal discussions that were necessary to promote the idea. The scientific community was informed about the aims and methods of a scientific discipline sport informatics beforehand (Perl & Lames, 1995). The main intention of this article was to make clear to a broader community that informatics does not only provide tools for the work of sport scientists like text processing or statistics software. It offers also input at higher levels of scientific work, thus justifying the formation of a scientific discipline. The idea of interdisciplinary collaboration presented in this early article was implicitly a one-way model. Theories, methods, and tools from informatics should be applied to sports (see next section of this paper).

Soon after establishing a national association for sport informatics a new aim came into focus. The aim was to establish an international scientific association. There were good reasons to do so. As the world became a truly global village through advances in information and communications technologies, it became clear that in different parts of this village, people were addressing the same problems (Lames, 2008; Baca, 2006; Hughes, 2000; Perl, Lames & Miethling, 1997). In the area of game analysis one could for example mention the introduction of digitized boards, efforts to enter data by natural language detection software or the struggle for reliable computer-video couplings. These developments were brought forward independently for example at Mainz and Cardiff in the working groups of Jürgen Perl and Mike Hughes respectively (Lames, 2008).

After three international meetings in Cologne (1997), Vienna (1999) and Cardiff (2001) the International Association of Computer Science in Sport (IACSS) was founded at Barcelona in 2003 and Jürgen Perl became the first president. Since then, a series of biannual international conferences has been organized and members from different countries and almost all continents have joined the association. The future prospects of the association are excellent according to the present president, Arnold Baca, in his welcome message at the 11th German Workshop on Sport and Informatics at Augsburg, Bavaria, in 2008. The unique combination of sport science and informatics with the large application field of sports at any level provides these excellent perspectives. Nevertheless, the remarkable developments of the two sciences involved and in the field of sports make it necessary to reflect periodically on the levels achieved in interdisciplinary cooperation between the fields and the concept of sport informatics.

Interdisciplinarity in Sport Informatics

At first this section outlines the interests in cooperation between computer science and sport science in common projects. While the motive of sport science is quite obvious, that of computer science needs more elaborate discussion. The second part poses the question, which quality of interdisciplinarity between sport science and computer science exists today and which quality would be desirable and realistic in future? This is done by discussing existing models of interdisciplinarity and proposing a classification for research activities in sport informatics.

Common fields of interests – Why do computer science and sport science cooperate?

Here it is useful to differentiate between political, scientific and personal motivations behind cooperation. From a political perspective one must bear in mind that interdisciplinarity is considered an important research paradigm in most countries. The German Research Foundation (DFG), which is the central research funding organisation in Germany, holds the view that “scientific progress arises more and more at the borders and intersections of disciplines” (DFG, 2008). The national funding agency for sport scientific research in Germany (German Federal Institute of Sport Science) terms interdisciplinarity a “key element” of their founding policy. Announcement on funding initiatives refer to an “inter- and multidisciplinary approach […], integrated construction of theories, highly specialised choice of research methods and […] integrative presentation of results“ (BISp, 2008). While the precise meaning of such catch-phrases is somewhat clouded in jargon, a scientist, whose career depends on the positive evaluation (and funding) of his research projects, is ill-advised to refuse the commitment to interdisciplinarity.

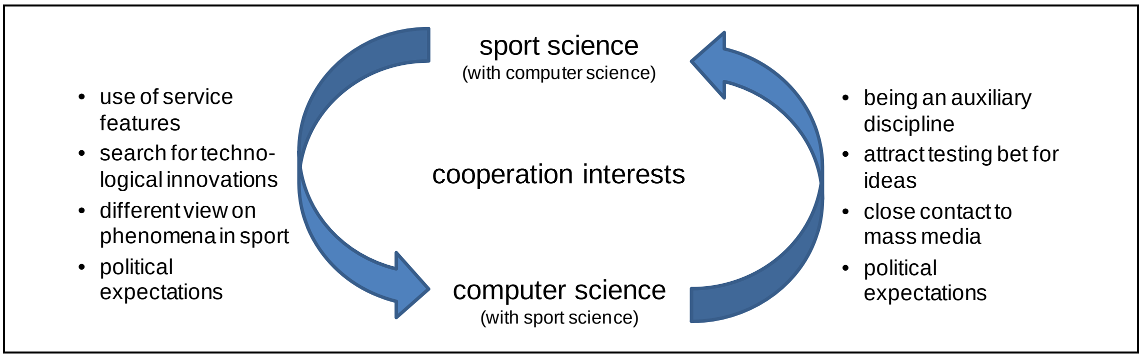

Fig. 3. Cooperation interests of computer science and sport science.

Sweeping aside this consideration, sound scientific justification for cooperation does exist (see Fig. 3). First of all - from sports science perspectives - computer science serves as an appreciated partner in those areas in which sports scientists do not excel themselves. This applies to data handling and software development, e.g. for the purpose of documenting training, controlling sensors or visualizing data. Second, information technology is an important source of innovations for training and competition. Collaborations with computer science help sport scientists to become aware of new technology and have the advantage of facilitating their availability in good time. Third, sport science expects that the approaches and perspectives of computer science should be transferable to the field of sport. For example the concept of soft computing can assist the understanding of phenomena in sport (see Section 3).

Less immediate are the benefits of cooperation with sport science from the computer science perspective. While traditionally computer science has supported other sciences, extending its own area of influence would not provide sufficient argument in favour of supporting projects in the field of sports. Of greater interests is the complexity of sport, which is well suited for testing and validation of methods and techniques of computer sciences. The existing structures in sports are neither too simple to be interesting, nor to complex to be described using mathematical models. One example of a problem is that of reconstructing human intention, e.g. as in the case of computer-aided crime detecting based on video recordings of surveillance systems (see Boghossian & Black, 2005). In fact sport science deals with sport games analyses in which similar computational requirements exists (automatic recognition of players, moves and strategies) albeit with reduced complexity (limited degrees of freedom, common rules, tactical invariants) is a similar problem. Computer science expects the development and validation of solutions for sports, to lead to knowledge, which then can be transferred to the initial problem. More generally speaking, sport could act as an attractive testing field for computer science, in which human behaviour can be observed and studied in a simplified, yet authentic field.

Additional motives for computer scientists are the societal relevance of sport and its huge role in mass media. This may give rise to the Basking in Reflected Glory (BIRG) phenomenon (Cialdini et al., 1976)). The “exotic” application field can also help them to build a reputation in the scientific community. Last but not least, many computer scientists, working with sport science, a personally involved in sport. Even if collaboration cannot be fully justified on the basis of individual involvement, political considerations and increasing publicity seem to have importance as secondary motives.

Quality of Interdisciplinarity – How do computer science and sport science work (or should work) together?

There are many ways in which the concept of “interdisciplinarity” has been classified by philosophy of science. One milestone in nomenclature was a congress in the year 1972, where the OECD proposed a classification of interactions between disciplines (OECD, 1972). In terms of this definition, multidisciplinarity is a juxtaposition of various disciplines without a connection between them. Interdisciplinarity describes any interaction between disciplines, which can range from simple communication of ideas to the integration of concepts, methodologies and epistemologies. Transdisciplinarity is the highest degree of cooperation and stands for a common set of theories and axioms for a set of disciplines (Fig. 4). On this basis, enhanced models, focussing on different aspects of interaction were developed: Heckhausen (1972) for example identifies six types interdisciplinary research, Boisot (1972) advises three categories of interdisciplinarity, Karlquist (1999) lists five modes of interdisciplinarity (an overview is provided by Chettiparamb, 2007).

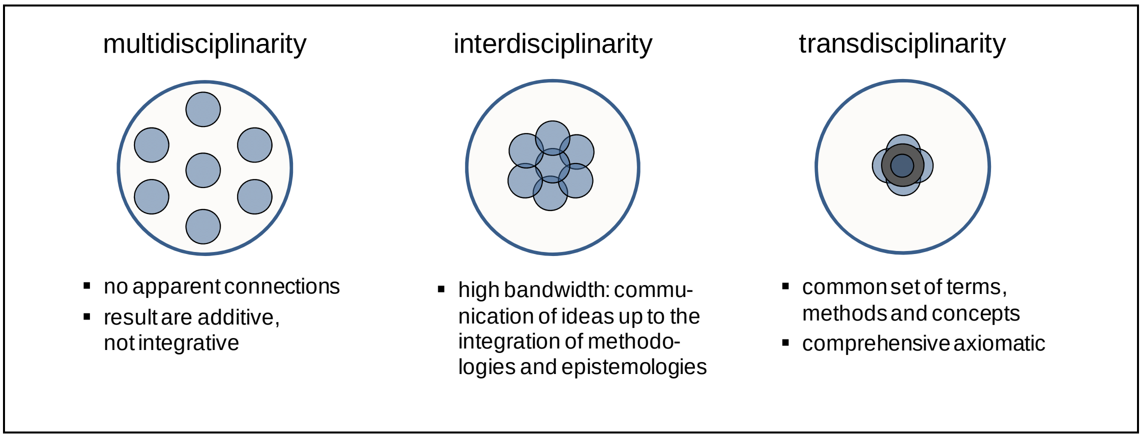

Fig. 4. Commonly used classification of types of interdisciplinarity (OECD, 1972).

When looking into the practice of sport informatics, it emerges that not any of these models is adequate to describe the existing interaction. The “borrowing“ of computer scientific methods (type a, b, c) matches to Heckhausens concept of *auxiliary-interdisciplinarity*. The simple usage of pre-defined tools (type a) corresponds to the OECD-term *multidiscplinarity*. The corporate development of tools/methods (type b) can be called *pseudo-interdisciplinarity* (Heckhausen) or *restrictive interdisciplinarity* (Boisot). The use of sport scientific knowledge in computer science (type d) accords with the idea of *structural interdisciplinarity* (Boisot). In this regard, this paper proposes an own classification, using four types of cooperation (see Fig. 5):

- Type a: Sport science applies existing approaches and tools from computer science. In this case, sports science does not take part in conceptualization and development. Computer science (or - being more precise - commercial software developing companies) only act as an anonymous service provider, without contact with sport science.
- Type b: Sport science integrates knowledge from computer science. This happens, when its own area of studies needs technical solutions, which do not exist on the market. Knowledge is assimilated either by acquiring the skills necessary or by entering into partnerships with computer science e.g. by means of student or third party funded projects. One aspect of this cooperation is that computer science provides nothing but skills in software development. There is no collaboration on a scientific level.
- Type c: Computer and sport science cooperate in research programs, which are in accordance with the research interest of both disciplines. Examples are the use of artificial neuronal networks for analyzing movement patterns or application of image recognition algorithms in sport game analysis. In this cases, computer science gets new insights by validating concepts and methods which have relevance for additional - perhaps more complex - problems. Sports science benefits from an improved and faster data acquisition and by getting a different perspective on the structures of sport.

- Type d: This type is comparable with type c, with the difference that paradigms and knowledge of sport science are used in computer science. An example would be the use of kinesiological models in controlling the motion of humanoid robots.

A review of the research activities in the last 20 years reveals that many projects of type a and b, but only a very few projects of type c and d can be found. One reason, why the popularity of sport informatics in the computer scientific community is not very high (there are computer scientists, who never heard about it or do not show interest in cooperation with sport science) might be, that there is often no genuine interdisciplinary research. A deeper concentration on those fields where computer science can profit from sport scientific paradigms and knowledge (types c and d), could improve the situation. This would require better communication of sport scientific expertise and recognition of sport as a fruitful application field for computer scientists (see Fischer, 1998).

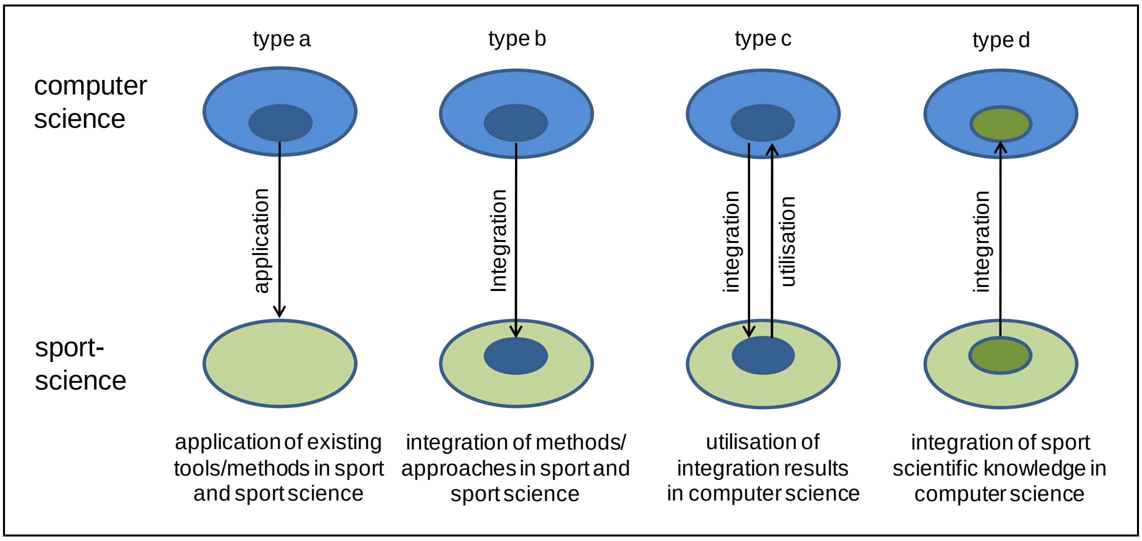

Fig. 5. Types of cooperation in sport informatics.

On the other hand, low affinity between the disciplines sports science and computer science must be taken into consideration. In contrast to other interdisciplinary linkages (like biology and chemistry, astronomy and physics or sociology and psychology), there is no common borderline, where one disciplines changes into another and no shared knowledge. Consequently sport informatics cannot be an autonomous inter-discipline like astrophysics or biochemistry. One-way-transfer is also a natural problem, because the processing of information is fundamental for all sciences, whereas the applications fields of computer sciences usually cannot provide any knowledge for the core area of computer science (apart from mathematics and electrical engineering). Even sport science and computer science have problems in creating real interdisciplinarity between their sub disciplines. They are both heterogeneous sciences without consistency in level of theoretical integration, axioms, methods and terminology (see discussion in Section 2). For this reason, while it is advisable to postulate and advance interdisciplinarity, it does well not to overcharge the idea of integration.

Mission statement – A self definition of sport informatics

Having the discussion of the last sections in mind, we suggest differentiating between sport informatics and computer science in sport. Computer science in sport stands exclusively for the use of computer technology in sport and sport science. Sport informatics also includes the application of methods and paradigms from computer/information science as well as from research programs, which try to transfer sport scientific knowledge to computer sciences. The following definition shows this enhanced self concept:

> Sport informatics is a set of multi- and interdisciplinary research programs at the interface of sport science and computer science. The materiel field is the application of tools, methods and paradigms from computer science on questions of sport science as well as the integration of sport scientific knowledge in computer science.

We can see in Figure 6 a diagram visualizing this standpoint: In both disciplines there is knowledge, that is potentially useful for the other discipline. Conversely there is a second area, which might be an application field for the findings of the other discipline. The research programs of sport informatics include parts of both disciplines and can be dedicated to one of the four types, identified in the last section.

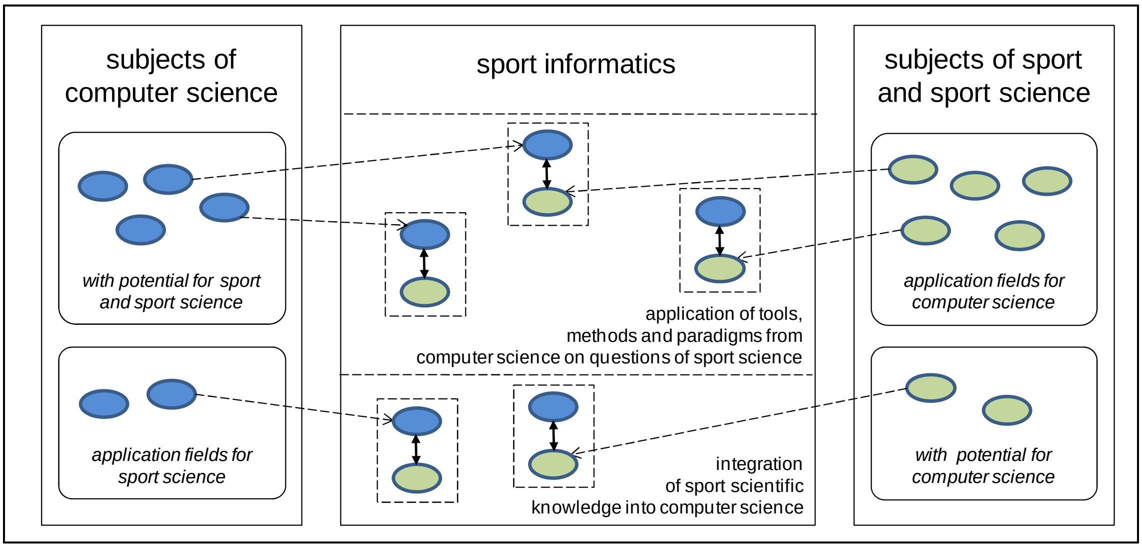

Figure 6. Basic structure of sport informatics. The discipline can be described as a set of multi- and interdisciplinary research programs. Most of these programs apply technological and methodological knowledge of computer science to study questions of sport science, but there are also some sport scientific findings, which can be useful for computer science.

Figure 7 shows a refinement of this rough structure by using a matrix with four areas. The upper both areas give examples for research fields for computer science with are useful for sport and sport science, the lower areas give examples, how computer science can profit from sport science. The next subsections discuss the two different directions of integration.

Computer Science in Sport Science

The first area in Figure 7 (top, left) shows topics in computer science, which may be useful for sport science. According to Perl and Lames (1995) we divide these area using two dimensions. The first dimension includes four main research areas of computer science, which are important to sport: (1) capturing and storing of data, (2) modelling, analysis and simulation, (3) presentation and visualization and (4) communication. The second dimension illustrates the idea, that the research field sport informatics is (or should be) more than just the simple application of tools for the recording, analysis and presentation of data. In addition to the “tool-level” (which is more information technology than computer science), there are also methods, theories and paradigms, which have a potential to support sport science (see cooperation types c and d in the last sections). The next paragraphs discuss some exemplary items in this sub matrix.

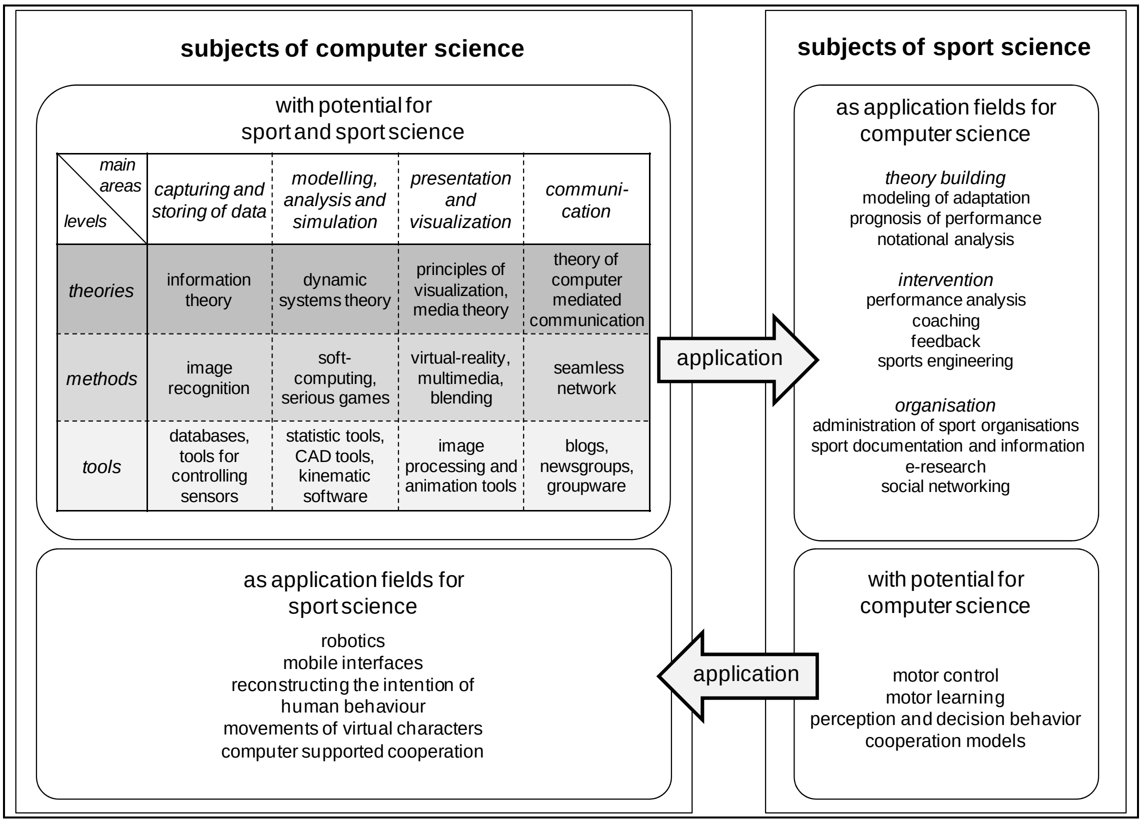

Figure 7. Subjects of sport informatics. The matrix shows examples for the research and application fields mentioned in Figure 6.

In the field of capturing and storing data, information technology provides for example database tools, which can be used for the storage of training and competition data (e.g. type, intensity and amount of training, tactical behaviour or performance) (Zeleznikow et al., 2009). This allows coaches to stay informed about the input load and the performance level of their athletes. Also many biomechanical devices like force plates, high speed cameras, GPS-devices and motion capturing systems use proprietary software tools controlling sensors and helping to manage measured data (Turner, 2009). For the modelling, analysis and simulation, sport scientists often make use of mathematical software like Matlab, Maple, SPSS or apply software for movement analysis. Sports engineers rely on tools for computer aided design (e.g. AutoCAD or Solid Edge) to develop new sports equipments.

Tools from information technology are also important for the presentation and visualization of data. In sport games for example, the linking of video sequences and databases is useful for game observation. In athletics or gymnastics, coaches use software, which allows to show additional information like force vectors, torsional movements or speed information inside a video or to superimpose pictures of two movements. Last but not least communication technology can help to organize sports: Today internet blogs or social networking websites are relevant for organizing training sessions and to find partners for team sports. Internet based groupware tools like synchronous video, video conference and whiteboards, supports athletes on international championships, by realizing communication with their coach at home (Link & Lames, 2005). In this context mobile devices for coaching become increasingly important (Link & Lames 2006; Novatchkov et al., 2009).

On the method level, computer science for example has developed techniques for image recognition, which can be helpful to capture positional and biomechanical parameters directly from video recordings (Beetz et al., 2005). Therefore computer science does not provide readymade tools, but rather general algorithms for colour, texture and shape comparison, which have to be adapted to the sport specific situation (see cooperation types b and c in the last section). In the field of analysis and simulation of sports, the methods of soft computing have become more important: artificial neuronal networks are used to simulate the relationship between training input and performance output in swimming (Edelmann-Nusser et al., 2002), to analyse tactical patterns in handball (Pfeiffer & Perl, 2006) or to identify movement patterns in basketball (Lamb, Bartlett & Robins, 2009). Generic algorithms help to find solutions in high dimensional configuration spaces e.g. to optimise the design for sport equipment (Vajna et al., 2006) or to optimise throwing movements (Bächle, 2003). Last but ot least, serious games can have a positive effect on perception, reaction and motor control and are potential useful for education and intervention in sports (overview is given by Wiemeyer, 2009).

At the theory level the theory of complex dynamic systems is an example that holds a lot of promises for sport science. Many processes in sport seem to base on non linear coupling rules, which lead to complex phenomena. The theory of complex systems helps to model and to understand for example interaction in sport games as well as processes of biological adaption due to training. Successful examples are perturbations (Hughes, Dawkins & David, 2000; Jörg & Lames, 2009), relative phases (Walter et al., 2007), chaos theory (Lames, 1999) of the paradigm of self organization (McGarry et al., 2002).

The second part of the matrix (top, right) shows examples for application fields in sport and sport science. These fields are structured which the headlines “theory building” (getting new theoretical insights into phenomena of sports), “intervention” (improving training and competition) and “organisation” (managing activities related to sport). Examples for these application fields are already mentioned in this section.

Sport Science in Computer Science

The third and fourth parts (bottom left and right in Fig. 7) shows examples for sport scientific knowledge fields, which are potentially useful for research in computer science. Here, no internal structure is needed - we just give three examples to make this direction more concrete.

The first example is software for the safe and autonomous operation of robots. Traditionally the algorithms for navigation, locomotion and objects grasping bases on two different concepts: planning and controlling (Latombe, 1991). Planning methods define the movements and the position of the joints at any time before the movement. This requires complete information about the entire environment and the objects to be manipulated. On the other hand, controlling methods rely on local status information during the movement, based on visual or force feedback. This allows reacting on unexpected events like obstacles, but without global information, it is not guaranteed, that the algorithm finds the (best) solution for a task.

Kinesiology knows that human motor control does not follow the planning or controlling paradigm, but it should better be described as self organizing process, influenced by both aspects. For example top level dart player show a substantial variability in velocity, joint angles and the sequential timing of body parts from trial to trial (Müller & Sternad, 2004). The presumably most important skill for elite players is to balance parameters during the movement and not to reproduce fixed motor programs. If sport science could understand this self organizing processes in detail, these finding could also be used in the development of new paradigms for controlling robots.

The second example is cooperation in sport games. An important factor for success in soccer is the quality of interaction between the players of a team. Interaction is needed on the level of the entire team, e.g. by shifting the team formation in dependency of the tactics and the position of the ball, as well as on the level of subgroups, for example when a striker starts running to receive a pass before the ball was played. Some of these interactions are highly trained - others arise spontaneous based on the situation. The conditions for successful or non successful interaction between players (e.g. which are components of decision making in soccer, which agreements are needed for organising the defence, which cues are used for the timing of a pass?) are of great interests for exercise science and sport psychology. If they could develop models how cooperation in sport games takes place in detail, these results would be valuable for computer scientific research fields like intelligent autonomous systems.

A third example can be found in the field of mobile computing. Mobile computing - which means the use of computers during movement - is a fast growing application field for information technology. Examples are the use of handhelds in medicine (documentation of patient records), in military (geographical information for foot soldiers) or in sport (feedback about physiological parameters). One important aspect is that mobile computers places extended demands on the user's coordination and cognition (Kjeldskov & Stage, 2004). While running or walking, he has to adjust the movements of the legs with the movements of the hand-arm-system. On a cognitive level the user must pay his main attention to his forward locomotion and at the same time, he has to look on the screen to coordinate his hand movements. Up to now, our knowledge about the interrelation between walking speed, heart rate, input, reading performance and interface design has been quite vague. Experiences and research methods from kinesiology and biomechanics can help computer science to develop user friendly human-computer-interfaces, which are even usable under physiological stress.

Perspectives for 2020

The last section of this paper provides a perspective on potential developments in the field over the next ten years. Two questions are in the centre of interest:

1. Which developments in the field of information and communication technology can be expected?
2. How can these developments be used in sport und sport science?

Even when nobody can forecast future developments in detail, it is nevertheless possible to pre-estimate, which technologies are on the top of the agenda. For this purpose we refer to a study which was commissioned by the German Federal Ministry of Education and Research (Oertzen et al., 2006). The study uses a Delphi method, which relies on the phenomena “wisdom of crowds” (Surowiecki, 2004). In two rounds, a panel of independent experts (n=681) from science, economy and confederations was asked, which information and communication technologies will become important in the next 20 years. The opinions were collected, summarized and reflected back to the members. In the second round the members were asked to revise the own answer with regard to the others. As a result, the study formulated several prospects about the engineering and temporal feasibility of technologies. Some of the predicted developments, that might have an impact on sport and sport science, are:

- Miniaturization and computing power: The physical barrier is still not reached and Moore’s law (number of transistors that can be placed inexpensively on an integrated circuit is doubling approximately every two years) will continue for at least ten years (Gelsinger, 2008). It is quite obvious, that the processing speed of a standard computer (price 1000$, see Kurzweil, 2005) will grow in similar dimensions.
- Network capability: Under everyday conditions, the data transfer rate will reach about 1 Gbit/s (today ca. 0,02 Gbit/s). This is true for wired data exchange via “the last mile” and also for stationary and mobile wireless systems. Wireless networks with a small range (e.g. WLAN) will reach this capacity earlier than wireless wide area networks (e.g. UMTS).
- Networking: Miniaturization of information technology will lead to an increasing integration of processing devices into everyday life (ubiquitous computing, pervasive computing). These autonomous devices can communicate spontaneously with each other via a self-configuring wireless network. This “internet of things” (ITU, 2005) bases on common standards and can use any network infrastructure that is available in the environment (seamless network).
- Cloud computing: Many companies will offer cloud computer services like common software, data storage and computational power via the internet. The running and maintaining of an own it-infrastructure is getting more and more unnecessary (Dikaiakos et al., 2009).
- Small, inexpensive processing devices: Using synthetic material and print technologies, it is possible to produce electronic devices very cheap. This makes it cost-effective to integrate them into objects for one way use.
- Power supply: The electrical power supply of mobile devices will stay a key problem. Hardware, which small energy requirements, like sensors or RFID-devices, can use alternative energies like body heat, kinetic energy, light or sound waves.
- Display technologies: Important developments in the field of display technologies will be small and lightweight data glasses and virtual retinal display, which can draw a raster display directly onto the retina of the eye.
- Geo-spatial positioning: Additional to the American NAVSTAR-GPS and the Russian GLOSNASS-System, the Galileo-System of the European Union will be available. In particular, the combination of the systems will allow a better coverage and accuracy (<1 m, at 95 % coverage) than today. Also image tracking and delay based approaches (microwaves) will lead to an improvement of position measurement (<10 cm, at 100 % coverage) in the close-up range.

- Speech recognition: Software that coverts spoken words to machine syntax will be able to recognize most speakers without training with an accuracy of more than 90 %.
- Software components: In software engineering, the importance of predefined software components will increase. The use of 3th party services will reduce the developing time about 50 %.
- Open source: The relevance of open source software and hardware will increase. About 50% of software will be available with its source code under relaxed or non-existent copyright restrictions.

Having this in mind the question arises, in which way these advancements can be useful for sport or sport science? The example of expert systems in sport showed in the middle of the 1990s, that even well-intentioned ideas sometimes fail to succeed in the sport market. The approach in this context was to integrate knowledge of from sport practitioners and sport scientists into computer systems for training diagnosis and intervention. Even if some example for such experts systems in sport were developed (Lee & Kim, 1992; Pizzinato et al., 1998; Zeleznikow et al., 2009), a resounding success of the concept is still missing. The reasons for this are the missing quality of technological implementation (e.g. failing pattern and speech recognition, useless statistical reporting) on the one hand, as well as missing demand from coaches and athletes on the other.

This example shows that it is quite difficult to appraise, which scientific concept can hold its ground in the dichotomy of sport market pull and technology push. Nevertheless, the following prospects P1 up to P10 try to give an optimistic outlook, how information and communication technology will be used in sport related training, competition and education in the year 2020. This “Forecast Sport Informatics 2020” considers open issues and demands from sport and sport science and the technological developments mentioned above (publications in brackets show first approaches or technological overviews):

P1 Positioning systems and lightweight sensors can be used for the capturing of total physiological and positional data (Eskofier et al., 2008). This information will be provided to trainers, athletes and mass media in real time.

P2 Based on the enhancements in the field of artificial intelligence, tactical behavior in sport games can be analyzed automatically (Atkinson & Rojasa, 2009).

P3 Virtual environments can simulate many different sports close to reality (Bideau et al., 2004). This allows a training of perception, cognition and decision in sport specific situations.

P4 New display technologies will be integrated in sport clothes (e.g. sun glasses) (Rolland & Cakmakci, 2009) and provide athletes with information during training and competition.

P5 Sport uses smart clothes including sensory (measuring and transmitting of data) and actuator (adaption of material characteristics) features for diagnosis, prevention and performance improvement (Borges et al., 2008).

P6 Biomechanical models can simulate human movements perfectly, without using motion capturing or key frames (Natural Motion, 2006). This allows the animation of virtual characters (e.g. for computer games), which look and move exactly like humans (Horswill, 2008). These models can also be used to make the motor behavior of humanoid robots more manlike.

P7 Simulation has become an important research tool for natural scientific disciplines. The simulation of training processes (e.g. performance adaption) can replace the real experiment in many cases (Ganter, Witte & Edelmann-Nusser, 2006; Churchill, Sharma & Balachandran, 2009).

P8 The increased computational power and cloud computing services allow simulating the vibration, flow and gliding of sport devices and athletes more realistic than today (Levy & Katz, 2007).

P9 The relevance of sport clubs as a local organizer of training sessions decreases. Group building via social networks on the internet gets more important for everyday sportspersons.

P10 In-class lectures at universities will lose their importance. Almost 50 % of theoretical courses and seminars in sport science will be replaced by online equivalents.

The realization and implementation of these scenarios needs both: the development and adaptation of technologies as well as the mutual exchange of sport science, computer science, sport federations and sport practitioners. Important factors for success are the added value, alternatives available, costs, usability and market acceptance of new innovations.

Conclusion

The paper has shown options for reasonable and fruitful liaisons between sport science and computer science. They hold a set of advantages for both disciplines, if projects are designed and performed with the view on genuine interdisciplinary research. As scientific progress in this area is closely connected to technological progress, sport sciences is well advised to monitor developments and to integrate partners from computer science into own research activities. Important technological improvements will be increased computing power and network capacity, networks concepts such as ubiquitous or pervasive computing, small and cheap one way electronics, thin and flexible displays as well as better speech recognition and geo-spatial positioning technologies. These technologies have a potential impact e.g. on the measurement and reporting of physiological and positional data, on computerized performance analysis, sport clothing and the quality of computer simulations in the fields of sports engineering, motor behavior and physiological adaptation. Certainly, it is the main work task for the computer-science-in-sport-community to make sure, that a check-up of the given forecast in the year 2020 - maybe on a symposium of the International Association on Computer Science in Sport - will be as successful as possible.

References

Atkinson, J. & Rojasa, D. (2009). On-the-fly generation of multi-robot team formation strategies based on game conditions. *Expert Systems with Applications*, 36(3), 6082-6090.

Baca, A. (2006). Computer science in sport: An overview of history, present fields and future applications (Part I). *International Journal of Computer Science in Sport, 5* (Special edition 2), 25-35.

Bächle, F. (2003). The optimisation of throwingmovements with evolutionary algorithms on the basis of multi-body systems. *International Journal of Computer Science in Sport (Special Edition 1)*, 6-11.

Beetz, M., Kirchlechner, B. & Lames, M. (2005). Computerized Real-Time Analysis of Football Games. *IEEE Pervasive Computing*, 4 (3), 33-39.

Bideau, B., Multon, F., Kulpa, R., Fradet, L. & Arnaldi, B. (2004). Virtual reality applied to sports: do handball goalkeepers react realistically to simulated synthetic opponents?. *Proceedings of the 2004 ACM SIGGRAPH International Conference on Virtual Reality Continuum and Its Applications in Industry* (pp. 210-216). New York.

BISp (2008). German Federal Institute of Sport Science. Press release from 2008-04-19. Access from http://www.bisp.de (welcome page) (19.05.2008).

Boghossian, B. & Black, J. (2005). The challenges of robust 24/7 video surveillance systems. *IEE International Symposium on Imaging for Crime Detection and Prevention (ICDP 2005)*, 33-38.

Boisot, M. (1972). Discipline and interdisciplinarity. In OECD (Ed.), *Interdisciplinarity: Problems of Teaching and Research in Universities* (pp. 89-97). Centre for Educational Research and Innovation (CERI). Paris: OECD Publications.

Borges, L. M., Rente, A., Velez, F.J., Salvado, L.R. Lebres, A.S., Oliveira, J.M., Araújo, P. & Ferro, J. (2008). Overview of Progress in Smart-Clothing Project for Health Monitoring and Sport Applications. *Proceeding of ISABEL 2008 - First International Symposium on Applied Sciences in Biomedical and Communication Technologies*. Aalborg, Denmark.

Cialdini, R.B., Borden, R.J., Thorne, A., Walker, M.R., Freeman, S. & Sloan, L.R. (1976). Basking in reflected glory: Three (football) field studies. *Journal of Personality and Social Psychology, 34*, 366-375.

Chettiparamb, A. (2007). *Interdisciplinarity: a literature review*. The Interdisciplinary Teaching and Learning Group, University of Southampton. access from http://www.heacademy.ac.uk/ourwork/networks/itlg (15.05.2008).

Churchill, T., Sharma, D. & Balachandran, B.M. (2009). Correlation of novel training load and performance metrics in elite cyclists. *Proceedings IACSS09, 7th International Symposium of the International Association of Computer Science in Sport* (pp. 24-34). Canberra, Australia.

Claus, V. (1975). *Einführung in die Informatik* (Introduction to “Informatik”). Stuttgart: Teubner.

DFG (2008). German Research Foundation. Founding Policies. Access from http://www.dfg.de (welcome page) (19.05.2008).

Dikaiakos, M.D., Katsaros, D., Pallis, G., Vakali, A. & Mehra, P. (Eds.) (2009). IEEE Computing - Special Issue on "Cloud Computing", *IEEE Computing*, 12(5).

Edelmann-Nusser, J., Hohmann, A. & Henneberg, B. (2002). Modelling and prediction of competitive swimming performance in swimming upon neural networks. *European Journal of Sport Science*, 2(2), 1-10.

Engesser, H. (Ed.) (1988). *Duden „Informatik“: ein Sachlexikon für Studium und Praxis*, Stichwort Informatik (Encyclopaedia „Informatik“, Keyword „Informatik“). Mannheim: Dudenverlag.

Eskofier, B., Hartmann, E., Kühner, P., Griffin, J., Schlarb, H. Schmitt, M. & Hornegger, J. (2008). Real time surveying and monitoring of Athletes Using Mobile Phones and GPS. *International Journal of Computer Science in Sports*, 7(1), 18–27.

Fischer, G. (1998). Transcending Cultures - Creating a Shared Understanding between Computer Science and Sport. In J. Mester & J. Perl (Eds.), *Sport und Informatik V* (pp. 43-52). Köln: Strauss.

Ganter, N., Witte, K., & Edelmann-Nusser, J. (2006). Performance prediction in cycling using antagonistic models. *International Journal of Computer Science in Sport*, 5(2), 56-59.

Gelsinger, P. (2008). Opening keynote of Pat Gelsinger (Senior Vice President Intel). Intel Developer Forum (IDF) Shanghai 2008.

Grupe, O. (1971). Sportwissenschaft. Aufgaben und Probleme einer neuen Disziplin (Sport science. Tasks and Problems of a New Discipline). *Attempto*, 47/48, 20-26.

Heckhausen, H. (1972). Discipline and Interdisciplinarity. In OECD (Ed.), *Interdisciplinarity: Problems of Teaching and Research in Universities* (pp. 83-89). Centre for Educational Research and Innovation (CERI). Paris: OECD Publications.

Höner, O. (2001). Interdisziplinäre Theorienbildung als Leitorientierung für den sportwissenschaftlichen Nachwuchs(?) (Is Interdisciplinary a Profitable Research Paradigm for Young Scientists?). *Zephir*, 8(1), 16-29.

Horswill, I. (2008). Lightweight Procedural Animation with Believable Physical Interactions. *IEEE Transactions on Computational Intelligence and AI in Games*, 1(1), 39-49.

Hoyningen-Huene, N. & Beetz, M. (2009). Rao-Blackwellized Resampling Particle Filter for Real-Time Player Tracking in Sports. In A. Ranchordas & H. Araujo (Eds.), *Proceeding of Fourth International Conference on Computer Vision Theory and Applications (VISAPP)* (pp. 464-470). Lisboa, Portugal.

Hristo Novatchkov, Philipp Kornfeind, Sebastian Bichler, Arnold Baca (2009). Mobile Coaching. *Proceedings IACSS09, 7th International Symposium of the International Association of Computer Science in Sport* (p. 145). Canberra, Australia.

Hughes, M. (2000). Computers and Performance Analysis in Sport. In A. Baca (Ed.), *Computer Science in Sport* (pp. 83-102). Wien:öbv & hpt.

Hughes, M. D., Dawkins, N. & David, R. (2000). Perturbation effect in soccer. Notational Analysis of Sport III, UWIC, 1-14.

ITU (2005). *The Internet of Things.* International Telecommunication Union (ITU) Internet Reports 2005. Geneva.

Jörg, D. & Lames, M. (2009). Perturbationen im Tennis – Beobachtbarkeit und Stabilität (Perturbations in Tennis – Observability and Stability). In M. Lames, C. Augste, O. Cordes, Ch. Dreckmann, K. Görsdorf & M. Siegle (Eds.), *Gegenstand und Anwendungsfelder der Sportinformatik. 7. Symposium der dvs-Sektion Sportinformatik vom 22.-24. Mai 2008 in Augsburg* (pp. 86-96). Hamburg: Czwalina.

Karlqvist, A. (1999). Going Beyond Disciplines: The Meanings of Interdisciplinarity. *Policy Sciences*. 32 (4), 379-383.

Kjeldskov, J. & Stage, J. (2004). New techniques for usability evaluation of mobile systems. *International Journal of Human-Computer Studies*, 60(5-6), 599-620.

Kurzweil, R. (2005). *The Singularity Is Near: When Humans Transcend Biology*. New York: Viking Books.

Lamb, P., Bartlett, R. & Robins, A. (2009). Self-Organizing Maps: An Objective Method for Clustering Complex Human Movements. *Proceedings IACSS09, 7th International Symposium of the International Association of Computer Science in Sport* (pp. 100-108). Canberra, Australia.

Lames, M. (1999). Football: A Chaos Game? Applying elements of chaos theory to the genesis of goals in football. In P. Parisi, F. Pigozzi & G. Prinzi (Eds.), *Sport Science ´99 in Europe* (p. 543). Rome: Rome University.

Lames, M. (2008). Coaching and Computer Science. In P.Dabnichki & A. Baca (Eds.), *Computers in Sport* (S. 99-120). WITPress: Southhampton.

Latombe, J.C. (1991). *Robot Motion Planning* (Chapter 1). Boston: Kluwer Academic Publishers.

Lee, J.-W. & Kim, K.-J. (1992). Development of an expert system for diagnosis and training prescription of cardiorespiratory functions in athletes. In G. Tenenbaum, T. Raz-Liebermann & Z. Artzi (Eds.), *Proceeding of the international conference on computer applications in sport and physical education* (pp. 277-284). Netanya, Wingate Institute, The Zinman College.

Levy, R. & Katz, L. (2007). Virtual Reality Simulation: Bobsled and Luge. IACSS07, *6th International Symposium of the International Association of Computer Science in Sport* (pp. 241-251). Calgary: Canada.

Link, D. & Lames, M. (2005). Effects of Computer Mediated Communication on the Quality of Beach Volleyball Coaching Sessions. In F. Seifriz, J. Mester, J. Perl, O. Spaniol & J. Wiemeyer (Eds.), *1st International Working Conference IT and sport and 5th Conference dvs-Section Computer Science in sport - Book of Abstracts* (p. 172-176). Cologne: Cologne Sports University.

Link, D. & Lames, M. (2006). Handhelds in der wissenschaftlichen Trainingsberatung (Handhelds for Coaching). In K. Witte, J. Edelmann-Nusser, A. Sabo & E.F. Moritz (Hrsg.), *Sporttechnologie zwischen Theorie und Praxis IV (S. 199-208).* Aachen: Shaker Verlag.

Luft, A. L. (1992). Grundlagen einer Theorie der Informatik – „Wissen" und „Information" bei einer Sichtweise der Informatik als Wissenstechnik (Basics of a theory of “Informatik”). In W. Coy, F. Nake, J.-M. Pflüger, A. Rolf, J. Seetzen & R. Stransfeld (Eds.), *Sichtweisen der Informatik* (pp. 49-70). Braunschweig/Wiesbaden: Vieweg-Verlag.

McGarry, T., Anderson, D. I, Wallace, S. A. , Hughes, M. D. & Franks, I. M. (2002). Sport Competition as a dynamical self-organizing system. *Journal of Sports Sciences*, 20, 771-781.

Miethling, W.-D. & Perl, J. (1981). *Computerunterstützte Sportspielanalyse (*Computer supported notational analysis*).* Ahrensburg: Czwalina.

Müller, H. & Sternad, D. (2004). Decomposition of variability in the execution of goal-oriented tasks: Three components of skill improvement. *Journal of Experimental Psychology: Human Perception and Performance*, 30, 212-233.

National Research Council (2004). *Computer science: Reflections on the Field, Reflections from the Field*. National Academic Press.

Natural Motion. (2006). *Euphoria:core motion synthesis library*. Natural Motion Inc.

Novatchkov, H., Kornfeind, Ph., Bichler, S. & Baca, A. (2009). Mobile Coaching. *Proceedings IACSS09, 7th International Symposium of the International Association of Computer Science in Sport* (p. 145). Canberra, Australia.

Nygaard, K. (1986). Programm Development as a Social Activity. In H.J. Kugler (Ed.), *Information Processing 86* (Proc. 10th IFIP World Computer Congress '86, Dublin) (pp. 189-198). Amsterdam: Elsevier Science Publishers B.V.

OECD (Ed.)(1972). Interdisciplinarity: Problems of Teaching and Research in Universities. Centre for Educational Research and Innovation (CERI). Paris: OECD Publications.

Oertzen, J., Cuhls, K. & Kimpeler, S. (2006). Wie nutzen wir Informations- und Kommunikationstechnologien im Jahr 2020? Ergebnisse einer Delphi-Befragung (How Do we Use Information and Communication Technologies in the Year 2020, Result of a Delphi Survey), *FAZIT-Schriftenreihe, Band 3*, Stuttgart, access from http://www.fazitforschung.de (15.05.2008).

Perl, J. & Lames, M. (1995). Sportinformatik: Gegenstandsbereich und Perspektiven einer sportwissenschaftlichen Teildisziplin (Sport Informatics Subject Matters and Perspectives of a Sport Scientific Sub Discipline). *Leistungssport*, 25 (3), 26-30.

Perl, J., Lames, M. & Miethling, W. (Hrsg.). (1997). *Informatik im Sport. Ein Handbuch* (Computer Science in Sport*)*. Schorndorf: Hofmann.

Pfeiffer, M. & Perl, J. (2006). Analysis of Tactical Structures in Team Handball by Means of Artificial Neural Networks. *International Journal of Computer Science in Sport*, 5 (1), 4-14.

Pizzinato, A., Denis, G., Vachon, G. & Kohler, F. (1998). Knowledge based system for the simulation of decision-making of the serve return phase in tennis: "LIFT"-system. In J. Mester & J. Perl (Hrsg.), *Sport und Informatik V (pp. 141–145).* Köln: Strauss.

Recla, J. & Timmer, R. (Eds.)(1976). *Kreative Sportinformatik. (Creative Sport Informatics). Der Internationale Jubiläums- Kongreß 1975 in Graz*. Schorndorf: Hoffmann.

Ries, H. & Kriese, H. (1974). Scientific model for a theory of physical education and sport sciences. In U. Simri (Ed.), *Concepts of physical education and sport sciences* (pp. 175-198). Natanya.

Rolland, J. & Cakmakci, O. (2009). Head-Worn Displays: The Future Through New Eyes, Optics & Photonics News, 20, 20-27.

Röthig, P. & Prohl, R. (Eds.) (2003). *Sportwissenschaftliches Lexikon*, Stichwort Sport (Encyclopaedia of sport science, keyword sport). Schorndorf: Hofmann.

Surowiecki, J. (2004). *The wisdom of crowds. Why the many are smarter than the few and how collective wisdom shapes business, economies, societies, and nations.* New York: Doubleday.

Turner, T. (2009). A WI-FI Based Embedded System for Biomechanical Data Telemetry. Proceedings IACSS09 (pp. 197-202). 7th International Symposium of the International Association of Computer Science in Sport. Canberra, Australia.

Vajna, S., Edelmann-Nusser, J., Kittel, K. & Jordan, A. (2006). Optimisation of a bow riser using the Autogenetic Design Theory. In I. Horváth & J. Duhovnik (Eds.), *Tools and Methods of Competitive Engineering Vol. 1* (pp. 593-601). Ljubljana: University of Ljubljana.

Walter, F., Lames, M. & McGarry, T. (2007). Analysis of Sports Performance as a Dynamical System by Means of the Relative Phase. *International Journal of Computer Science in Sports*, 6 (2), 35-41.

Wiemeyer, J. (2009). Digitale Spiele – (k)ein Thema für die Sportwissenschaft?! (Digital Games – Interesting or Not-interesting for Sport Science?). *Sportwissenschaft,* 39 (2), 120-128.

Zeleznikow, J., MacMahon, C. & Barnett, T. (2009). Providing automated decision support for elite athletes. *Proceedings IACSS09, 7th International Symposium of the International Association of Computer Science in Sport* (pp. 240-248). Canberra, Australia.