Report from Dagstuhl Seminar 13272

Computer Science in High Performance Sport – Applications and Implications for Professional Coaching

Edited by

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Abstract

This report documents the program and the outcomes of Dagstuhl Seminar 13272 "Computer Science in High Performance Sport – Applications and Implications for Professional Coaching". There were 25 presentations organized into 5 sessions over the course of three days focusing on various aspects on the relevance, applications and current issues pertaining to computer science in sport and it's applications for professional coaching. Each session covered miscellaneous topics that looked at its broad topics ranging from hardware devices for mobile coaching, modelling sports as dynamical systems, use of neural networks in performance analysis as well as theoretical issues in human movement science, and serious games. Once again the Dagstuhl seminar concept provided benefits for the experts from different fields and countries that otherwise would hardly meet and have the opportunity to exchange their ideas in an informal way. Several ideas were presented aiming to reduce the gap between sport science and high performance coaching. New projects were discussed among the participants, such as the agreement to build a data repository in order facilitate the collaboration between different institutions with common and complementary research topics or framework in performance analysis.

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1 Executive Summary

António Lopes

From June, 30^{th} to July, 3^{rd}, 2013 a seminar on "Computer Science in High Performance Sport – Applications and Implications for Professional Coaching" was held at Schloss Dagstuhl – Leibniz Center for Informatics. After 2006, 2008, and 2011 this seminar was the fourth on computer science in sport that was held in Dagstuhl.

Following the tradition, this seminar brought together experts from computer science together with experts from sports science to explore the options of interdisciplinary work.

This year emphasis was put on the interface between computer science and the high performance sport, in particular on coaching. The seminar focused on barriers that prevent coaches from embracing sport and computer science, and, how data can be presented in a more meaningful way so that coaches' expertise is enabled by science.

During the seminar, several participants presented their current research lines, ongoing work and open problems were discussed, focusing on three sub-themes: (1) coach-specific computer applications to address issues of communication and real-time application, (2) the pipeline from data acquisition to processing to analysis to visualization, and (3) modelling and simulation.

Twenty-seven invited participants, among which there were sports and computer scientists and coaches, gave a total of 25 talks and had enriching discussions about sport science. Problems, solutions, and benefits between computer science and sport science into high-performance coaching were discussed, and considered current developments in data acquisition, positional tracking, filtering, signal processing, game modelling, match analysis, performance analysis and optimization, computer-supported training, computer visualization and communication, 3D motion reconstruction, and serious games.

Abstracts of the presentations given during the seminar as well as abstracts of seminar results and ideas are put together in this paper. The first section describes the seminar topics and goals in general.

Once again, the Dagstuhl seminar concept provided benefits for the experts from different fields and countries that otherwise would hardly have met for an opportunity to exchange their ideas and inspire visions for the future of computer science and sport science in professional sport and coaching in an informal way. Several ideas were presented to reduce gap between sport science and high performance coaching and new projects were discussed among the participants. Discussion led to current and future trends and challenges that require implementation on high performance sports coaching, such as: mobile computing, multimedia, data visualization, performance reconstruction and real time feedback.

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3 Overview of Talks

3.1 Intelligent Systems

Arnold Baca (University of Vienna, Austria)

Joint work of Baca, Arnold; Kornfeind, Philipp; Tampier, Martin

Athletes and coaches require effective methods to support and guide the training process. Our approach is based on a feedback system providing mobile and almost real time solutions for wireless body sensor data transmission, processing and feedback provision. The concept of the system [1] helps to adapt and evaluate certain performance parameters in respect to the individual performance level. Characteristic parameters of the physical activity can be supervised continuously. In this way coaches are able to guide a number of athletes individually and the athletes get feedback of the quality of their motion which helps to interpret the body's reactions to physical load. For such purposes, sensors, carried by the person or mounted onto the sports equipment, are used to measure different parameters of an exercising person. These parameters are sent to a smart phone application via ANT+^{TM}.

The measured data is then transmitted to an application server using wireless communication technologies (UMTS, HSUPA). Based on the collected data feedback instructions can be generated by experts and sent back to the exercising person [2]. Sub-modules are currently integrated into the server application thus implementing intelligent algorithms for processing the acquired data. In this way feedback instructions may automatically be generated. The actual implementation of the system for running, for example, includes an intelligent feedback module for guiding further execution [3]. Load-based performance development is predicted by applying the antagonistic meta-model PerPot [4].

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3.2 Monitoring load and recovery in sports

Michel Brink (University of Groningen, the Netherlands; Hanze University of Applied Sciences, Groningen, the Netherlands)

Joint work of Lemmink, Koen

This talk will focus on the delicate balance between load and recovery in sports. In order to improve performance athletes continuously challenge their personal boundaries. This may lead to a local or general overload of the human body that results into injuries, illnesses or the overtraining syndrome.

Monitoring load and recovery possibly may help to optimize performance and prevent athletes from health related problems. A theoretical framework that contains physical and psychosocial load and recovery components is presented. It is suggested that the total amount of load should be in balance with the total amount of recovery for optimal performance. Analyses could focus either on a comparison of individuals to their peers or a comparison with personal history data. Careful documentation of load, recovery and performance, by means of logs, questionnaires and field tests, seems a useful approach to detect a disturbed balance and guide intervention strategies.

3.3 Monitoring training in team sports: An example from professional team sports

Aaron Coutts (University of Technology, Sydney, Australia)

A major challenge for scientists working with professional team sports is being able to individualize training to meet the needs of both the individual and team. Due to the unpredictable nature of team sports, the training requirements of individuals within the same team can be diverse (i.e., dependent upon positional roles, recovery rates, experience etc.), and often requires careful monitoring and control so that performance is optimised. This is particularly relevant during periods of regular competition where the risk of maladaptive training is increased, and small changes in athlete readiness status can affect individual and team performance. Indeed, research has shown that overreaching can occur in team sport athletes with only a relatively small increase in the training load above what is considered "normal". Therefore, an important issue for the coach/scientist is having access to monitoring systems that accurately assess how players are coping with training and responding to training and match stimuli [1].

In this presentation, a theoretical model for monitoring team sport athletes will be provided. Additionally, we will provide a working example of current monitoring tools used in team sports, discuss logistical issues in implementing such a system, and present practical models of how data can be analysed to provide accurate and timely feedback to coaches. These will be supported by examples demonstrating how this approach has been used to inform coaches how athletes are coping with training and then used to guide decision-making about future training. Discussion of the role of computer science in modelling training responses and predicting performance and injury risks will be provided.

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3.4 The interpersonal coordination dynamics underlying individual and team tactical behaviours in soccer

Ricardo Duarte (TU Lisbon, Portugal)

This communication will join some different studies under development illustrating the general framework we are using to capture individual and team tactical behaviours in soccer. As a general idea, we use player positional time-series data in order to analyse the interpersonal coordination tendencies than underlie the emergence of tactical behaviours. But, how can one transform these data into meaningful information? One way to capture the interpersonal coordination dynamics is using compound positional variables integrating relevant physical constraints associated to the performance field.

In respect to individual tactical behaviours, our efforts have been directed to determine the different performance profiles according to playing positions. Player-to-locus distance, the individual dominant region areas and the number of intra- and inter-team local spatial interactions showed important differences between playing positions. The defensive players and the inner midfielders showed less mean player-to-locus distances. Also, from defenders to forwards and from internal to external positions, there was a decrease in the number of local spatial interactions with teammates and an increase in the number of local spatial interactions with opponents. Inner midfielders displayed the lower areas but the higher total number of local spatial interactions.

In regards to team tactical behaviour, some compound positional variables such as surface area, stretch index, team width, team length, contraction-expansion speed and collective velocity have been used to capture specific team tendencies. Nowadays, we are integrating these continuous variables with some categorical variables such as having or not ball possession and the corresponding field zone. Data suggested, for instance, an increase in the predictability of teams' tactical behaviours over the course of the match, independently of the phase of the game.

3.5 Wearable computing systems for feedback applications in sports

Björn Eskofier (University of Erlangen-Nürnberg, Germany)

Wearable computing systems play an increasingly important role in sports. They comprise of two parts. Firstly, sensors embedded into equipment are used for physiological (ECG, EMG, ...) and biomechanical (accelerometer, gyroscope, ...) data recording. Secondly, embedded microprocessors or wearable computers are used for the analysis of the recorded data. Together, these systems provide support, real-time feedback and coaching advice to sportsmen of all performance levels.

The talk focuses on four of the most prevalent challenges that have to be addressed in order to implement wearable computing systems: 1) integration: sensors and microprocessors have to be embedded unobtrusively and have to record a variety of signals 2) communication: sensors and microprocessors have to communicate in body-area-networks in a secure, safe and energy-saving manner 3) interpretation: physiological and biomechanical data have to be interpreted using signal processing and pattern recognition methods 4) usability: interaction with the systems is provided by human-machine-interfaces (HMIs) that have to be intuitive and adapted to several use cases.

3.6 Science and Professional Coaching – still on hold

Sofia Fonseca (Lusófona University, Lisbon, Portugal)

Joint work of Fonseca, Sofia; Lopes, António

Following wise recommendation of Jäger and colleagues [1], the spatial organization of teams and players has been considered by various authors to study interaction behaviour in team sports, since players' distribution in the field is likely to mirror their individual and collective tactical options [2]-[4], and hence useful to characterize tactical performance. This approach has been generally accepted and it has been effectively embraced in recent studies [5]-[7], however, there is less consensus regarding the definition of the set of variables that are considered to describe interaction behaviour at different levels (team, player). Such variables, which can be viewed as individual and collective performance indicators, should be defined based on the game principles, tactical concepts and, ultimately, should represent a major source of information to high performance coaches, with whom a connection has not been yet fully established. Recent work on this topic was presented [8]-[10] in order to share and discuss ideas on this subject; and particularly to understand how relevant these could be on a practical context and which directions should be given to these so that this work can truly help and support professionals in high performance sports.

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3.7 Team Training Control in Cycling: Development and Application

Thomas Jaitner (TU Dortmund, Germany)

Due to the immense progress in information technologies and microelectronics during the recent years online monitoring of trainings parameters can be provided in many sports. To date, a main research focus in this area is on data acquisition and pre-processing by mobile devices with limited energy and computing resources as well as on communication infrastructure that even support remote analysis and feedback by distant experts within one training session. Less attention has been on how the huge amounts of sensor data can be processed and analysed to support or even autonomously control training.

This talk focuses on an example for an information technology based training optimization that has been developed to control team training in semi professional youth cycling. In group training, the power output depends on the position of the rider in the group. In slipstream it can be reduced up to 36% while reaching the same speed than on first position. Consequently, the cardiovascular and the metabolism load are reduced in rear positions (Neumann, 2000). For optimal group training, speed, formation, position of each cyclist within the group and the rotation sequence must be adapted to the individual performance potential of each athlete. The concept of the Team Training Control System including hardware components, software components and mathematical algorithms for training control as well as the results of the first experiments with different linear and non-linear control algorithms will be presented. Practical consequences for the application of the TCTS as well as the usability of the system are in main focus of the discussion.

3.8 Bridging the gap between computer science and practice in golf

Peter Lamb (TU München, Germany)

The sport of golf is one in which many coaches are open to using new technology. This situation presents an opportunity for computer science and practice to have a positive interaction. The current standard for golf swing analysis is based on comparing swing parameters of a client to a model of a correct swing, which is derived from a database of swing data taken from elite golfers. While this approach is well received by coaches and players, the logical next step is to develop an approach to look at adaptability in movement patterning. The majority of studies on human movement variability show us that no matter how skilled an athlete is, each movement is a response to the specific constraints affecting the performance. Here was presented an approach to interacting with coaches on what the "correct" swing means, and ideas to use technology to incorporate findings from motor control and motor learning in the diagnostic package.

3.9 Computerized Game Observation in Goalball

Daniel Link (TU München, Germany)

Joint work of Link, Daniel; Weber, Christoph

Goalball is a Paralympic Sport for blind athletes. There are three players on each side who try to score by rolling the ball into the opposing net, past the defending team. Each player wears a blindfold so that each player is visually impaired equally. There are bells in the ball so that the players can echolocate it when it is moving. The current project has developed software, specifically for performance analysis in Goalball ("Goalscout" and "Goalview"). The software operates on tablet PCs for intuitive scouting to be efficient for the user. Furthermore, it generates positional data from the video frame which leads to precise information. The purposes of this project were to: a) design a prototype software, which can analyse performance efficiently and, b) analyse key aspects of Goalball.

From the Paralympic Games 2012 in London, all men's and women's games (17) from knockout matches were recorded and analysed with a prototype of the new developed software. Throwing patterns were characterized for various teams. For example, the Finnish and Brazilian Men's teams avoided throwing from Sector 9 (both just 2%). The Finnish team threw from the outer Sectors 73% instead of the middle sectors. The Brazilian team preferred to throw from Sectors 2, 5, 6 and 7. Goal-Sectors distributions were balanced, especially the Brazilian team. Finland tried to score on borderline sectors 3 and 4 and on outer sectors 8 and 9. General throwing patterns for individual teams should be used in forming a defensive strategy. Further research should investigate the underlying reasons for the observed throwing patterns. The developed software will allow such questions to be addressed.

3.10 Finding the I(nteraction) in TEAM

António Lopes (Lusófona University, Lisbon, Portugal)

Joint work of Fonseca, Sofia; Lopes, António; Baca, Arnold; Leser, Roland

In this talk, we presented a point of view about the relationship between professional coaching, computer scientists and sport scientists, bringing to discussion some key points on how the latter can interact in a high performance environment, and presenting an approach to build a Multilevel Sports Analysis Intelligence System (MSAIS) software.

The empathy for the different goals, particularly between sport scientists and coaches, seems to be the main gap for a fruitful joint work in high performance sports coaching. If professional coaches need to rely on meaningful data, they would need experts in the field to gather and process them to be easy to understand. These experts could be sports scientists that have some of the expertise/education required to do this assessment. On the other hand, sport scientist need good quality data to better perform their expertise in this field, but these data are, most of the time, not accessible due to coaches and clubs' professional and legal issues. The successful cooperation between coaches and sport scientist lies in the answer, of the latter one, to the question: what can you do to help the coach to win? Although sport scientist cannot predict or prescribe the recipe to a successful season, they can effectively help to improve teams and coaches performance if they understand the high performance sports' environment, the game in depth and have something practical to add to the coaches goals. In our point of view, the first step is to feel empathy to the coaches profession (sacked if does not win) and the last step will be to submit high performance players to contextualized tests or task. Between these two steps, there is a lot of ground to cover, for instance gain coaches and teams trust and this can only be done by spending time in the club and, most of the times, just listening and observing. By getting deep knowledge of the surrounding environment, it will be easier to interact and communicate with the coaches and their empathy towards the sports scientist goals will develop until the sport scientist is recognized as team member.

There is not a known model suitable to engage all high performance sports' scenarios, but in the end, this interaction between coaches, sport and computer scientists in finding the right place and timing to develop their roles, is all a matter of trust. Moreover, trust needs to be built, as is a major part in the foundation of a successful interpersonal relationship. Another topic presented in this talk, was the Multilevel Sports Analysis Intelligence System (MSAIS) project that focus the interactive dynamics for visual analysis and its related issues. Coaches need to rely on meaningful and contextualized data, thus, automatic and fast assessment systems for tactical performance in team sports are today demands for any team. The validation of a new kind of assessment tool of tactical performance could provide the licensing of an innovative software system, one that could integrate an automatic live data collection and generate, in short real time, crucial information (i.e. pattern and error detection…) and reports for coaches to an online platform (see www.videobserver.com).

Finally, the talked ended with the announcement that a Portuguese Association Computer Science in Sport is established and this organization could work as an aid to bridge the gap between coaches, computer scientists and sport scientists by promoting their interaction in common activities.

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3.11 Automatically Creating a Computerized Expert for Live-Action Sports

Patrick Lucey (Disney Research, Pittsburgh, USA)

In February 2011, "Watson" (an IBM created AI computer system capable of answering questions) competed on Jeopardy! and comprehensively beat the best human players in the history of the quiz show. The technology of "Watson" evolved from IBM's "Deep

Thought" and "Deep Blue" projects in the 80's and 90's where they created a computer system which could beat the top human chess players. In sports, AI computer systems have been developed to automatically generate text summaries using match statistics (e.g. statsheet.com), although the reporting lacks tactical insight. Video games (e.g., EA Sports) have virtual commentators, which can describe and analyse what is going on in the match. Following this trend, we ask "why can't a computer system do similar things for real live-action sport?"

Enabling a computer to understand live-action sports is extremely difficult. Unlike chess and quiz shows, live-action sports have continuously changing variables with no guaranteed structure. Furthermore, whereas video games have the luxury of omnipotent knowledge about the virtual world, systems designed to understand the real world must be able to interpret noisy and missing sensor data (e.g. player and ball tracking). Like any other expert, the computer system needs to have seen an abundance of specific sports action to recognize patterns and explain why these are relevant and interesting. Obtaining exemplary data is an arduous task (i.e. capturing, sensing and annotating), and there are many technical challenges for real-time operation. Although challenging, the potential benefits of a computerized sports expert is enormous in both broadcasting and coaching domains. In this talk, I will first give an overview of the emerging field of sports-analytics and describe why such a system is a necessity. I will then talk about some of our recent work at Disney Research Pittsburgh in developing a computerized sports expert, specifically focussing on our work in: 1) automatically characterizing and recognizing team tactics in soccer, 2) Forming a representation of player tracking data which enables large-scale analysis of team behaviour and 3) automatically predicting shot-type and location of shots using Hawk-Eye tennis data.

3.12 Representing ball movement trends in football using an interactive visualization method

Stuart Morgan (Australian Institute of Sport, Australia)

Progress in computer science in areas such as machine learning, pattern detection and computer vision, is remarkably fast moving. Primary reasons for this are that problems are well defined, research groups have access to common data sets, and published papers frequently include source code and performance metrics that allow direct comparison to future approaches. Although some aspects of computer science in sport involve applications of existing solutions to new sport-related problems, there remain many areas in this field where novel solutions to technically difficult problems exist. For instance, understanding group behaviour in competitive and constrained tactical games is a difficult problem that is yet to find a satisfactory theoretical framework.

It is proposed that the computer science in sport community could address these challenges by increasing the efficiency of the international research effort. Common data sets and well-defined problems can accelerate progress in the understanding of performance in high performance sport. Also, providing open source solutions with novel published research allows other research groups to compound progress for the betterment of the entire computer science community. Therefore, it is proposed that an open source code base be established that incorporates novel and important work by international researchers in computer science in sport, which is freely available to researchers subject to non-commercial Creative Commons license constraints. Further, rich, diverse and common data sets should be also made available to allow international research groups to compare, verify and accelerate the progress in computer science in high performance sport.

3.13 On winning the penalty shoot-out in soccer: Revisited

Tim McGarry (University of New Brunswick, Canada)

The penalty shoot-out is used to break tied games in the knock-out stages of soccer (football) competition. Its great importance in determining tournament outcomes is observed in the following descriptive statistics obtained from the 1976 European Championships through the 2010 FIFA World Cup. In 9 of 17 (53%) instances at least one of the two finalists won a penalty shoot-out earlier in that same competition, eight (47%) tournament winners won a penalty shoot-out, with three (18%) final games themselves being decided by penalty shoot-out. These statistics demonstrate that any team with design of winning a knock-out football tournament may well have to win a penalty shoot-out in pursuit of that aim. Thus, teams should prepare in advance for the reasonable likelihood of contesting a penalty shoot-out.

The shoot-out comprises of five alternating penalty kicks per team with each kick taken by a different pre-designated player from the available on-field players remaining at the final whistle. The highest tally of goals from five attempts each determines the winning team with equal tallies subsequently broken by "sudden death". In "sudden death" the next player per team is assigned a penalty kick in iterative fashion until a result is determined (i.e., one team scores and the other team misses on the same penalty kick pairing). Since each on-field player is awarded a single penalty kick, the line-up order in which penalty kicks are taken opens the possibility of optimized decision-making for influencing the final outcome. Using probability analysis and computer simulation, the following pre- and post-game strategies were identified. First, the best five penalty-takers should be assigned to the five penalty berths in reverse order, that is, the fifth best penalty-taker should take the first penalty kick, the fourth best penalty-taker the second penalty kick, and so on. In the event of sudden death, the sixth ranked penalty-taker should take the sixth penalty kick, the seventh ranked penalty-taker should take the seventh penalty kick, and so on. For this strategy to be used, the entire squad of players should be ranked a priori on their penalty-taking ability. The goalkeepers should likewise be ranked a priori on their penalty-stopping ability. These findings furthermore highlight possible consideration of tactical substitution of on-field players for higher ranked penalty takers, including higher ranked penalty stoppers (goalkeepers), in view of an impending penalty shoot-out.

These results are of practical importance in that they are shown to maximize the likelihood of winning a penalty shoot-out under certain initial conditions. Should the initial conditions change, then a different optimized line-up order would be expected, but the general underpinnings of identifying a priori an optimized line-up sequence, and the corresponding implications for effecting this optimized decision in sports practice by means of advance preparation, holds.

3.14 Process-oriented qualitative game analysis

Jürgen Perl (University of Mainz, Germany)

Joint work of Perl, Jürgen; Memmert, Daniel

Obviously, description and analysis of a complex game cannot be reduced to distributions of numbers but needs the dynamics of the playing processes. Therefore, success of a specific activity cannot be measured just by a ratio without setting it into relation to the situations in which it was used. The software-tool SOCCER, which has been developed in a cooperation of computer science and sport science, meets the demands by a combination of conventional data analysis, dynamic state-event-modelling and artificial neural networks: In particular, recognition of creative activities and simulation of their effectiveness in the con-text of game situations is of interest. However, different from normal process patterns, creative ones show two properties which make the net approach difficult: They fluctuate with time, and they are comparably seldom. In order to overcome those problems, a new type of network has been derived from the self-organizing network DyCoN, combining the learning dynamics with a fractal topologic dynamics: The basic structure of the TriTop approach (Triangular Topology) is a triangle of neurons, which by embedded new neurons iteratively is divided into three new triangles, causing the following effect: If adding new neurons with frequent information under the aspect of similarity, the corresponding starting triangles condense to clusters of refined ones. If adding a new neuron with rare information, which is not similar to any other, it stays isolated and therefore will be saved as a creative one.

3.15 Measuring Tactical Performance in Soccer

Jaime Sampaio (University of Trás-os-Montes, Vila Real, Portugal)

Joint work of Sampaio, Jaime; Goncalves, Bruno; Folgado, Hugo; Therón, Roberto

Our research team is exploring how soccer players' dynamic positional data can be used to assess tactical performance, by measuring movement patterns and inter- player coordination. The data is used to calculate overall, sectorial and position- specific centroids and, afterwards, the players' and dyads' distances, angles and coupling to these collective attractors is presented in co-variation with several situational variables (game location, game status, quality of opposition). Data analysis is processed with non-linear statistical procedures, such as approximate entropy, to identify the amount of randomness in each time series; and relative phase, to identify different modes of coordination (in-phase, anti-phase and transitions) during the matches dynamics. The results are be complemented with visual analysis tools to improve the understanding of emergent self-organization behaviours and the dynamic functional constraints at the scale of the environment.

3.16 Critical power models in endurance sports

Dietmar Saupe (University of Konstanz, Germany)

We develop methods for data acquisition, analysis, modelling, optimization and visualization of performance parameters in endurance sports with emphasis on competitive cycling. We use a differential GPS device (Leica GPS900) to extract high-precision trajectories of real cycling tracks. The equilibrium of the pedalling force Fped and resistance forces defines the relation between pedalling power Pped and cycling speed (P-v-model). The resistance forces are composed of the gravitational force, aerial drag, frictional losses in the wheel bearings, rolling resistance the inertial force as well as the slipstream force.

This model is implemented in our software that controls the brake force of a commercial Cyclus2 ergometer (RBM Elektronik). A prominent feature of our setup is that the Cyclus2 is controlled not via the standard TCP-IP interface, but via the RS232 interface, which allows us to control the torque of the eddy current brake and to measure the angular speed at a sampling rate with up to 40 Hz instead of only 2 Hz. Additionally, a cyclist and bicycle management, synchronized videos of the cycling tracks, an electronic gear shifter and the recording and visualization of various performance parameters during a ride are the main features cycling simulator. Furthermore, we use an SRM cycling power meter in conjunction with the Garmin Edge 800 bicycle computer to measure the performance parameters in the field. The model and the simulator setup have been validated by comparing outdoor speed and power measurements to model simulations as well as measurement on the simulator for real cycling tracks.

In order to optimize the pacing strategy for time trials of a specific cyclist on a specific bicycle and track, we use established physiological endurance models, such as the 3-parameter critical power model. Such models depict the endurance of a cyclist as a dynamical system and are often visualized as hydraulic models. Their major characteristics are a limited pedalling power contribution by the aerobic metabolism (critical Power Pc), a constrained anaerobic capacity Ea that an athlete can use to exceed the aerobic power for a limited time, as well as constraints on the maximum power Pm of the athlete, which is a function of the remaining anaerobic capacity.

The optimal pacing is defined as the pacing that ensures that the cyclist finishes the track in minimum time subject to the constraint that the physiological condition of the cyclist is always within an admissible range. Mathematically, this can be formulated as an optimum control problem, where the pedalling power is the control variable and the state variables are distance, speed and quantities that define the physiological state (ean). One major future goal of the Powerbike Project is to extend the physiological model to e.g. Morton's 3-component hydraulic model, and to improve its calibration in order to compute realistic optimal pacing strategies for cycling time trials, which are useful for athletes in practice. Moreover, an extension to a modelling of road cycling races with two or several cyclist using differential game theory is envisioned.

In the Dagstuhl presentation I will focus on the physiological modelling aspects, review the critical power concept, the measurement of the parameters, and some recent extensions that were proposed to generalize the model. It is an open issue, to what extent these models can be used to yield realistic optimal control solutions for time trial pacing strategies.

3.17 Effects of sensorimotoric insoles on gait pattern of adults

Wolfgang Schöllhorn (University of Mainz, Germany)

Joint work of Schöllhorn, Wolfgang; Eekhoff, Alexander; Hegen, Patrick

Traditionally, professional coaching is firstly oriented on archetypes of average world class athletes and secondly based on the assumption that an intervention does have the same, or at least, similar effects on all athletes. The identification of individual high performance athletes on the basis of time courses of kinematic and dynamic variables led to question traditional professional coaching. Furthermore, the identification of emotions or even of music which people were listening to during walking destabilized the classical point of view. The aim of the present investigation was to test the influence of active insoles as an example of intervention on the gait pattern of adults during the same and during different days.

Five male and five female subjects wore active insoles (Medreff) during walking over a force plat form and filmed by 8 Infrared cameras. Kinematic and dynamic data of 5 double step cycles were recorded on three days before, during, and after (situations) wearing active insoles. Four nonlinear (2x MLP, 2x SVM) and one nonlinear (cluster-analysis) pattern recognition approach were applied to all time courses of 3D-angles and angular velocities of the lower extremities during a single double step.

The results revealed individual recognition rates up to 100% for persons and for days by means of SVM. Situations (b, d, a) were recognised by rates of 87–95%. Again the dominance of individuality could be verified. Furthermore, short term influences of the insoles on gait patterns could be shown. Alltogether, the results question classical professional coaching and favor highly individual and situative training.

3.18 Game Analysis using the ISOPAR Method

Michael Stöckl (University of Vienna, Austria)

In game sports, single athletes or teams can be treated as complex dynamical systems. Thus, measurements of performance of athletes and teams are collective parameters which describe the outcome of the dynamical systems. In game sports the location where a performance takes place plays an important role, because the location already determines a certain amount of the constraints which influence and guide an athlete's or a team's performance. Therefore, the idea of the ISOPAR Method is to provide an opportunity to analyse performance with respect to the location where it occurred. Based on discrete measurements of performance, a continuous topology of performance is calculated across the field of play. The ISOPAR Method offers the opportunity to visually analyse sports performance using the ISOPAR maps which visualize such topologies of sports performance on a map of the pitch similar to the well- known isobar maps which illustrate barometric pressure. Such ISOPAR maps have already been used to analyse the performance of single shots of PGA Tour golfers and to identify difficulties at golf holes. Furthermore, the ISOPAR Method was used to study the performance of free kicks with respect to the respective outcome in women's soccer. ISOPAR maps were also used to investigate the play in field hockey and how it is influenced by the fact that there only is a right-handed stick in this sport.

3.19 Tactical performance assessment by measuring collective behaviour of football players

Anna Volossovitch (TU Lisbon, Portugal)

Players' positional data represents a relevant source of information. The spatial-temporal variables provide a consistent measure of team behaviour when considered simultaneously. However there are several questions concerning these variables: Could collective positional variables be used as measures of a quality of performance? How do players behave in successful and unsuccessful situations? Does collective behaviour change in function of players' expertise level? In our research the compound positional variables (team length, width, surface area and stretch index) were used to analyse the team performance in specific situation of match play and in a small-sided games. The results show that compound positional variables are able to reflect the variability of the offensive and defensive team behaviours of young players of different ages and expertise levels. Further research is needed to evaluate the potential generalization of these findings in order to understand better whether these compound variables can be considered as reliable performance indicators in monitoring of learning and performance during long-term soccer training.

3.20 Optimising Pacing Strategies for Team Pursuit Track Cycling

Markus Wagner (University of Adelaide, Australia)

Joint work of Wagner, Markus; Day, Jareth; Jordan, Diora; Kroeger, Trent; Neumann, Frank

Team pursuit track cycling is a bicycle racing sport held on velodromes and it is part of the Summer Olympics. It involves the use of strategies to minimize the overall time that a team of cyclists needs to complete a race. We present an optimisation framework for team pursuit track cycling and show how to evolve strategies using metaheuristics [1] for this interesting real-world problem. Our experimental results show that these heuristics lead to significantly better strategies than state-of-art strategies that are currently used by teams of cyclists.

References

1 M. Wagner, J. Day, D. Jordan, T. Kroeger, and F. Neumann, Evolving Pacing Strategies for Team Pursuit Track Cycling, in in Advances in Metaheuristics, Operations Research/-Computer Science Interfaces Series, Springer, 2013.

3.21 Computer Science in Sport at the University in Magdeburg, Germany

Kerstin Witte (University of Magdeburg, Germany)

The purpose of this short presentation is the introduction of the several fields of computer science in sport in our department with applications. Especially, I talk about following topics (1) Development and Optimization of Sport Equipment by Integration of Measuring and Information Systems, (2) Possibilities for determination of anticipation under laboratory and field conditions (software, video presentation, virtual reality, recording of interaction by motion capturing), (3) Match analysis in Combat Sport, (3) Modelling (biomechanical modelling, using nonlinear approach for technique analysis and performance analysis).

4 Working Groups

The Dagstuhl Seminar on "Computer Science in High Performance Sport – Applications and Implications for Professional Coaching" had a mixed groups of presentations during the three days. The overview of each session is presented next.

4.1 Day 1, Session 1

Speakers: Jürgen Perl, Sofia Fonseca, Ricardo Duarte, António Lopes, Michael Stöckl
Chair: Jaime Sampaio

Jürgen Perl was the first presenter to discuss his work on process oriented qualitative game analysis for football for which he introduced the software SOCCER. This software combines the conventional data analysis with dynamic state-event-modelling and artificial neural networks for the recognition of creative activities and their effectiveness in the context of the game. To overcome the difficulty to detect patterns stemming from rare events such as creative activities he presented TriTop, which is a type of network that derived from DyCoN, combining the learning dynamics with a fractal topologic dynamics that allows to isolate the neurons that carry information about rare events and that can be saved as creative ones.

Following, Sofia Fonseca provided a talk on the use of spatial metrics to characterize tactical organization and reminded that there still is a lack of scientific knowledge on the set of variables that can be used to assess team sports performance. She stated that those variables should be defined on well-known game principles and tactical concepts thereby effectively representing the source of information to high performance coaches. She also pointed out the limitations of some commonly cited spatial metrics variables (surface area, stretch index, team width, team length) and the outstanding characteristics of the Voronoi diagrams approach and related variables recently used in the literature.

Next, Ricardo Duarte gave a communication that showed different studies under development to capture individual and team tactical behaviours in soccer in order to analyse the interpersonal coordination tendencies. These sets of studies are trying to gather useful information by the transformation of the position data of players using variables such: player-to-locus distance, dominant region, and the number of intra- and inter-team local spatial interactions to determine player profiles according to their playing positions and compound positional variables such as surface area, stretch index, team width, team length, contraction-expansion speed and collective velocity to capture team characteristics. Regarding individual tactical behaviour he stated that player-to-locus distance, the individual dominant regional areas and the number of intra- and inter-team local spatial interactions had exhibited important differences between playing positions. Considering the collective tactical behaviour, preliminary results indicate an increase in the regularity of the teams' tactical behaviours over the course of the match, independently of the phase of the game.

The fourth presentation was made by António Lopes and was titled Finding the I(nteraction) in TEAM. This presentation looked upon the communication and interaction process between professional coaches, computer and sport scientists from different point of views. This first issue gave rise to a discussion on how sport and computers scientist should interact with professional coaches and on the importance of understanding the different goals, roles and tasks that everyone has in order to improve this fruitfully synergic collaboration. The second matter presented was the Multilevel Sports Analysis Intelligence System project that focuses on the interactive dynamics for visual analysis and its related issues and characteristics to provide meaningful, contextualized and easy to understand data. This talked ended with the announcement that a Portuguese Association Computer Science in Sport is established and this organization could work as an aid to bridge the gap between coaches, computer scientists and sport scientists by promoting their interaction in common activities.

The last presentation of the morning was made by Michael Stöckl and he talked about the application of the ISOPAR method in game analysis of golf, free kicks in soccer, field hockey, and tennis. This method allows the analysis of performance with respect to the location where it occurred. This method consists in the creation of a continuous topography of performance based on discrete measurements that is calculated across the playing field. This method differs from the heat maps as it has the possibility to weight values.

4.2 Day 1, Session 2

Speakers: Martin Lames, Björn Eskofier, Wolfgang Schöllhorn, Michael Brink, Aaron Coutts, Chikara Miyaji
Chair: Stuart Morgan

Martin Lames was the first presenter of this section, with a presentation entitled Theory and practice of computer scientist intervening in practice, where he started to talk about the different types of knowledge: theoretical and applied. To make his point he developed a pie chart for the various concepts of science and sport, followed by the distinct type of research that can is being done in sports science: basic, applied and for evaluation. This allowed the participants to have a picture and to discuss about the different purposes that can drive the goals of a sport scientist (from a practical side into scientific problem or vice-versa) and to gain insight about epistemological concepts and models.

Björn Eskofier made the following presentation about wearable computing systems for feedback applications in sports. He introduced the team that works with him and showed how wearable computing systems are divided in physiological and biomechanical data recording devices whose embedded microprocessors allow to analyse the collected data. He described the four of the most prevalent challenges that have to be addressed in order to implement wearable computing systems: (1) microprocessors must be embedded unobtrusively with the ability to record a variety of signals; (2) microprocessors have to be able to communicate in body-areas' networks in a sustainable manner; (3) the recorded data have to be interpreted using signal processing and pattern recognition methods and (4) the interaction with the systems has to be intuitive and adapted to several use cases. He showed some examples of hardware (Shimmer sensor platform) and the application for golf, MoGoPuCo. There were some questions in the discussion about the accuracy demands and about the training and competition gap.

Next, Wolfgang Schöllhorn gave a presentation on pattern recognition of movements and the impact of insoles to gait. He started by questioning the traditional coaching methods that are based on the assumption that an intervention has a similar effect on all athletes. He presented his research work that aimed to test the influence of active insoles on the gait pattern of adults during the same and during different days. For this, five male and five female subjects wore active insoles (Medreff) while walking over a force platform and were filmed by eight infrared cameras. Four nonlinear and one nonlinear analysis for pattern recognition were applied to all recorded data (before, during, and after wearing active insoles). His results revealed dominance of individuality verified by individual recognition rates up to 100% for persons and for days, by means of SVM. The presentation was wrapped-up by questioning the classical professional coaching that, unlike his research results show, do not take into consideration individual training.

The following presenter was Michael Brink who discussed a framework for the monitoring of physical and psychological load and recovery. His talk pointed out models of external and internal load and recovery giving rise to questions about their operationalization and the complexity of the system construct for the recovery, which depends on the measures of recovery (subjective and/or objective), on the system, the level, and the course.

Aaron Coutts then presented a theoretical working model for implementing a training monitoring system in a professional football club. He started by referring the main challenge of scientists working with professional team sports, namely being able to individualize training in order to meet the needs of both the individual and team, as players have different roles, recovery rates, experience, etc. So care is needed when monitoring and controlling training tasks in order to improve performance and to avoid overreaching (prevent injury) in players. This justifies the need to have systems that accurately assess players coping with training. Logistical issues and present practical models of data analysis were discussed and supported by examples of Australian football coaches in order to provide accurate decision-making and fast feedback.

Finally, Chikara Miyaji presented the SMART video database that appears motivated by the absence of specific media focused on sports movement. The idea is that this database should be an easy way to search in recorded shared videos, as a user, in first instance, will access the information based on the behavior of previous users, sorting what is important from non-important data. He presented his vision and an all-in-one camera prototype that will enable users to record, upload and store video data.

4.3 Day 2, Session 3

Speakers: Wouter Frencken, Jaime Sampaio, Anna Volossovich, Stuart Morgan, Daniel Link
Chair: Koen Lemmink

Wouter Frenken started this session. He mentioned the importance of a sport scientist to be close to the teams with whom he works as this proximity will improve the chances of him being recognized as a team member and consequently being integrated and included in the activities in the club. Following the topic of the present seminar, he has explained, also based on his experience, that the communication between sport scientists and coaches is essential to guarantee that the former understand the needs of the latter. Wouter has presented the INMOTIO software, which he is developing in his research, but pointed out that there is a mismatch between the outcomes of the software and the specificity of the coaches' requirements. The software is useful for scientific research, and the scientific issues that are in the table, but needs to be adjusted to respond to what coaches are interested in extracting from the game.

Next, Jaime Sampaio presented some of his studies, which aim to explore how soccer players' dynamic positional data can be used to assess tactical performance, by measuring movement patterns and inter-player coordination. He considers the teams' centroid positions as a collective attractor and studies how this relates with other measures, such as angles and distances, as well as situational variables (e.g., game location, game status, quality of opposition). Data is analysed by means of non-linear methods (entropy and relative phase), supported by visual analysis tools.

Following this, Anna Volossovitch presented her exploratory work on using various spatial metrics to assess performance in sports games and to identify behavioral patterns. She considered the teams' lengths, widths, surface areas and stretch indexes in specific situations of a match play in a small-sided game of soccer, played by young players of different ages and expertise levels. According to the obtained results, these variables reflect the variability of the offensive and defensive team behaviours. However, it is still not clear how these variables can effectively be used as performance indicators.

Stuart Morgan has gave his presentation on representing ball movement trends in football. The analysis is performed using a visualization technique based on the ISOPAR method previous presented by Michael Stöckl. During his presentation, he stated the current trend and importance to develop such systems for independent data exploration in an open source fashion. He showed a demo of an interactive tool called 3D View Kit and shared his vision of an Open Performance Analysis system and to find a community of practice. Some key points followed the discussion over incentives to people participation and requirements specifications for the system.

Daniel Link presented his research project that aimed to design prototype software that could be used to analyse key aspects of Goalball, which is a Paralympic Sport for blind athletes. This specific software, "Goalscout" and "Goalview", intends to be very intuitive and efficient for the user. The match statistics that one can obtain are throw techniques, throws and sectors (target – throws). Results from an application at the Paralympic Games 2012 in London, allowed the identification of throwing patterns for various teams which can be considered by coaches for forming defensive strategies. Still, further research is needed to improve this tool regarding the improvement of detection technique since it has some restrictions concerning throwing positions.

4.4 Day 2, Session 4

Speakers: Markus Wagner, Thomas Jaitner, Peter Lamb, Tim McGarry
Chair: Dietmar Saupe

The first speaker, Markus Wagner, presented a talk on Evolving Pacing Strategies for Team Pursuit Track Cycling. The aim of this work is to optimize pacing strategy by minimizing the overall time that a team of cyclists needs to complete a race. Wagner presented a novel application of metaheuristics to the optimisation of elite competitive track cycling, in which they have used a state-of-the-art evolutionary algorithm as a local optimiser for the power profiles called Covariance Matrix Adaptation Evolution Strategy (CMA-ES). Wagner's algorithm has led to better strategies than those described in the literature, and therefore have potential to aid athletes in improving their performance.

Next, Thomas Jaitner has addressed an issue that emerges from an online monitoring of training, which is a common practice in various sports these days. Namely, he has investigated how the huge amounts of sensor data can be processed and analysed to support or even autonomously control training, particularly in semi professional youth cycling. The individual training impulse in a group training depends on the position of the rider. The front rider has higher cardiovascular and metabolic demands in comparison with those in rear positions. Thus, for optimal group training, speed, formation, position of each cyclist within the group and the rotation sequence must be adapted to the individual performance potential of each athlete. Thomas has presented a Team Training Control System (TCTS) concept and has discussed the practical consequences for the application of the TCTS as well as its usability.

Peter Lamb has presented his work on technique analysis and coach interaction in golf, where some acoustic feedback is given to players as they prepare to shoot. He started by making an overview of the current standard for golf swing analysis. He pinpointed a possible next step by the development an approach that looks up to adaptability in movement patterning, in the response to specific constraints. His approach is based on the use of biomechanical characteristics of the swing that are captured by the sensors, which incorporate findings from motor control and motor learning into a "diagnostic package" to improve coaches' feedback.

Tim McGarry was the last speaker of this session, and he revisited one of his research topics, namely on winning the penalty shoot-out in soccer (football). The goal of this work was to present a model for selecting the appropriate line-up for the penalty shoot, as well as for a sudden-death event, given that any team to win a knock-out football tournament may well have to win a penalty shoot-out in pursuit of that aim. Hence, teams should prepare in advance for the reasonable likelihood of contesting a penalty shoot-out. In what is suggested by Tim, players and goalkeepers should be ranked a priori on their penalty-taking ability and penalty-stopping ability, respectively. Once these are ranked, and according to Tim's results on probability analysis and computer simulations, the suggested strategies are: First, the best five penalty-takers should be assigned to the five penalty berths in reverse order, that is, the fifth best penalty-taker should take the first penalty kick, the fourth best penalty-taker the second penalty kick, and so on. In the event of sudden death, the sixth ranked penalty-taker should take the sixth penalty kick, the seventh ranked penalty-taker should take the seventh penalty kick, and so on. As discussed in the end of this talk, there are a number of conditions that may change and influence the players initial ranking order (e.g., stress, injury during the game), however, and according to Tim's findings, the general underpinnings of identifying a priori an optimized line-up sequence, and the corresponding implications for effecting this optimized decision in sports practice by means of advance preparation, holds.

4.5 Day 3, Session 5

Speakers: Patrick Lucey, Josef Wiemeyer, Thorsten Stein, Arnold Baca, Kerstin Witte, Martin Lames
Chair: Martin Lames

This was the last session of the seminar. The first presentation was Patrick Lucey's introduction of large scale analysis of continuous sport using player roles. He started by giving an outline of the emerging field of sports analytics, describing the need of this field. Then he gave an overview of the recent work in the development of a computerized sports expert at Disney Research Pittsburgh (for ESPN), by focusing on three lines of R&D: (1) the automatic recognition of team tactics in soccer, (2) the representation of player tracking data and (3) the automatic prediction of shot-type and its location using Hawk-Eye tennis data. During the talk, he focused on the difficulty to generate automatic reports that contain tactical information, because a real live-action sport has continuously changing variables with no guaranteed structure, due to context interpretation (dynamic role and identity of players' representation, noise, missing data or flaws, etc..). Thus, computers will "struggle to understand" these dynamic structures, needing an abundance of data to be able to recognize and interpret patterns that are relevant in order to predict and produce automatic content. There is a need to work close with coaches to generate meaningful labels and problem definitions in order develop models that can assign role and identity representation (i.e. shape context, heat maps). He evidenced the potential benefits of a computerized sports expert in broadcasting domain by enabling the interaction of the audience in the game.

Josef Wiemeyer gave a talk about Serious Games presenting his recent research results on game experience for learning and training in sport. He started by presenting a four lens model framework to study the topic. He discussed the role serious games can play in health promotion (i.e. Nintendo Wii, Playstation Move) and discussed the relative transfer of skills from games to real life sport, as they can contribute to improve a number physical, social and psychological competencies. He showed some examples of good practice and the contribution to build personal learning environments. Still, the question remains: is there an effective transfer from virtual worlds to real world? The discussion followed with the suggestion of combining both virtual and real worlds as an approach to study serious games activities (i.e., augmented reality). He ended presentation promoting GameDays 2014 – 4th International Conference on Serious Games from April 1st to 4th at TU Darmstadt, Germany.

Following, Thorsten Stein presented the current and future research of robotics and motor learning. He gave an overview of how robotics can be used to investigate human motor adaptation and skill learning. He started to talk about the classic experimental design of motor adaptation experiments and the underlying theoretical considerations and gave a brief overview of current research topics and findings in the field of motor adaptation. Robot devices have been used to study motor adaptation tasks but also can be used for research in skill acquisition in sports. He evidenced some challenges regarding the use of robots in sports tasks like the upper limb movements that occur in 3D space and the forces that differ from those used in motor adaptation experiments; and that the relationship between motor adaptation and skill learning in sports is far from clear. Afterwards he talked about robotic guidance in motor learning (kinematic aspects of robotic guidance and dynamic aspects of robotic guidance) by presenting new developments in robotic devices, which can be used in the research of skill learning in natural movement tasks. Ideas on how the existing experimental designs need to be enhanced to be able to investigate skill learning with robotic devices were also a subject of discussion in his talk.

Arnold Baca made a presentation about his ongoing project on Intelligent Systems. The work consists in joint projects of wearable technologies (wireless sensors on athletes' sports equipment) and the use of positional data in order to develop mobile coaching (e-coaching) to aid athletes and coaches to support their training sessions. The idea consists in giving feedback in real time through the analysis of the performance data that is collected continuously, like the physical activity loads. This way coaches can guide training remotely and give real time assessment to athletes by smart phone application via ANT+^{TM}. He presented two examples, one on strength in rowing and another on running a marathon using mobile coaching. The interest in such kind of tools have led to the development of sub-modules into a server application to integrate intelligent algorithms processing collected data in order to automatic generate feedback instructions (i.e., load-based performance development using the antagonistic meta-model PerPot).

The discussion on this topic revealed the need to build a joint database of positional data for benchmarking in the sport science community in order to improve models for performance optimization and advanced data processing. At the end an announcement for the Conference of the German Association of Computer Science in Sport (dvs-Sektion Sportinformatik), from September 10th to 12th, 2014, Vienna, Austria, was made.

Following, Kerstin Witte presented the projects in the University of Madgeburg research center: (1) development and optimization of sport equipment by integration of measuring and information systems, (2) possibilities for determination of anticipation under laboratory and field conditions, (3) match analysis in combat sport and (4) modelling (biomechanical modelling for technique analysis and performance analysis).

Martin Lames, as one of the organizers and the new president of IACSS, closed this session and the seminar. He presented the IACSS and the next IACSS symposium on Darwin, Australia, from 22th to 24th of June 2014 and issues were discussed. The strategic need to develop a US representation and to attend the MIT conference was recognized. Another subject of discussion was education on computer science in sport and suggestions were made on organizing pre-conference workshops and on writing papers for IJCSS. The participants have agreed to build a data repository in order facilitate the collaboration between different institutions with common and complementary research topics or framework, and to apply a survey to study attitude and usage of ICT in (elite) sports. Finally, the organizing committee announced the organizers for the proposal for a possible follow up Dagstuhl seminar on computer science and sport.

Participants

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