

Modeling and Simulation of Sport Games, Sport Movements, and Adaptations to Training

Edited by

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Abstract

This report documents the program and the outcomes of Dagstuhl Seminar 15382 “Modeling and Simulation of Sport Games, Sport Movements, and Adaptations to Training”. The primary goal of the seminar was the continuation of the interdisciplinary and transdisciplinarity research in sports and computer science with the emphasis on modeling and simulation technologies. In this seminar, experts on modeling and simulation from computer science, sport science, and industry were invited to discuss recent developments, problems and future tasks in these fields. For instance, computational models are applied in motor control and learning, biomechanics, game analysis, training science, sport psychology, and sport sociology. However, for these models to be adequate, accurate and fully utilized to their potential, major inputs from both computer and sports scientists are required. To bridge the potential disconnect between the skill sets of both sets of experts, the major challenge is to equip both computer and sports scientists with a common language and skill sets where both parties can communicate effectively. The seminar focused on three application areas: sport games, sport movements, and adaptations to training. In conclusion, the seminar showed that the different application areas face closely related problems. The disciplines could mutually benefit from each other combining the knowledge of domain experts in e.g. computer vision, biomechanics, and match theory.

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1 Executive Summary

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Computational modeling and simulation are essential to analyze human motion and interaction in sport science, sport practice and sport industry. Applications range from game analysis,



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issues in exercising like training load-adaptation relationship, motor control and learning, to biomechanical analysis. New challenges appear due to the rapid development of information and communication technologies (ICT) as well as the enormous amount of data being captured within training and competition domains. The motivation of this seminar was to enable an interdisciplinary exchange between sports and computer scientists as well as sport practice and industry to advance modeling and simulation technologies in selected fields of applications: sport games, sport movements and adaptations to training.

From September 13 to September 16, 2015 about 29 representatives of science, practice and industry met at the Leibniz-Zentrum für Informatik in Schloss Dagstuhl to discuss selected issues of modelling and simulation in the application fields of sport games, sport movements and adaptation to training. This seminar was the fifth in a series of seminars addressing computer science in sport, starting in 2006. Based on previously selected issues, four main streams were identified:

- Validation and model selection
- Sensing and tracking
- Subject-specific modelling
- Training and sport games

The talks addressing these four topics are summarized in this report. They have been arranged according to the three main application fields: sport games, sport movements, and adaptations to training. In addition, generic comments on modeling in industry and science are presented. Moreover, the final discussion is summarized and a conclusion of the seminar is drawn.

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3 Overview of Talks: Sport Games

3.1 On the Use of Tracking Data to Support Coaches in Professional Football

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A new era in sports sciences is emerging with the advent of new digital tools for the analysis of athletes' training, performance and health. However, massive technological changes emerging over the past few years have led to a new issue, captured in the term Big Data. A clear challenge for sports scientists and practitioners is to understand which data matter and how to interpret them. The real challenge for the professional world is now to move from data-driven decisions to data-informed decisions. From this perspective, my talk addresses the question of investigating tracking data in football (i.e. both events data and players position in x,y,t coordinate) in order to derive meaningful and functional metrics. Broadly speaking, the idea is to overcome traditional generic statistics (e.g., number of passes done, number of shots, number of tackles, percentage of ball possession) by combining them into meaningful items for coaches and practitioners (i.e. information that can help them to make informed choices for recruitment, injury prevention or match analysis). More specifically, part of the work presented looked at the number of goals one could expect from a player, based on the location of the shots he took [1]. A model of expected goals per field position was derived from previous seasons and then compared to the actual number of goals scored by a specific player. This comparison can thus inform about the ability of this player to under- or overachieve in shots success. Looking at probability of scoring goals during a season, coaches can then be informed about conversion rate of a player, but rather than a raw goals/shots ratio, this goal expectancy metrics gives more context to the conversion ability (e.g., it can take into account the position of the shot, the defensive density during the shots). Combined to other measures like ball movement effectiveness, this kind of metrics can feed models of offensive contribution in professional football.

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3.2 The "Practical Impact Debate" in Performance Analysis

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Problem

Mainstream research in Performance Analysis (PA) applies traditional linear methods to data analysis, e.g. ANOVA. In this context, complex interactions in game sports are modelled quite poorly, e.g. quality of opponent is introduced as another static variable in a linear model: rank in final table of league [8, 9]. Fluctuations in behaviour, typically a constitutive pattern of game sports, are treated as measurement error and sought to be controlled by

enlarging sample size [3]. On the other hand, practical support is considered to be the main purpose of PA [6]. McGarry (2009) sees advancing the understanding of sports mainly with regard to improving future outcomes. In this situation, a review of Drust and Green (2013) gave rise to the “Practical Impact Debate”. The authors stated: “... it can be suggested that the influence of the scientific information that is available has a relatively small influence on the day-to-day activities within the “real world” of football.” (p. 1382).

The “Practical Impact Debate”

This statement was supported by a review of Mackenzie and Cushion (2013). They analysed existing PA-research and found widespread methodological problems as well as a missing research strategy for practical support. Carling et al. (2014) replied to this paper and – among other issues – defended analysts working in practice against some methodological criticism by the demands of conducting research in practical settings. He frequently referred to his earlier paper with the telling header: “Should we be more pragmatic in our approach?” [1].

Remarks on the “Practical Impact Debate”

The problem addressed has its root in a lacking distinction between applied and basic research. This issue is mentioned by Mackenzie and Cushion (2013) without drawing consequences for research strategies to be applied. In the eyes of the author it is helpful to distinguish between practical PA (PPA) and theoretical PA (TPA) [5]. TPA aims at clarifying the general structure of sports. It looks for general rules, appropriate models (dynamical systems modelling) and needs large, representative samples. PPA is in some respects the opposite. It may be defined as PA activities conducted in practice, i.e. analysing training and competition to support a team or a player. PPA is interested in any information that provides practical support and typically works with and for a single case, the own team or player. Moreover, practical consequences for training may not be found algorithmically from data collected but need a thorough interpretation with a background of in-depth knowledge from the many sources of information available in a professional football club (medical, physiotherapy, fitness, training are only the most important ones). So, in PPA – whether with or without methodological awareness – qualitative research methodology is used, which may be considered as a typical feature as well. With a basic distinction between TPA and PPA researchers analysing the general structure of performances are relieved from demonstrating an immediate practical use of their results, and analysts working in practice shouldn’t feel obliged any more to refute criticism from the point of view of basic research on their pragmatic solutions. Nevertheless, there is a tight connection between both areas. Measures in practice should be in agreement with general findings about the nature of the game, and in the other direction, findings in practice can give rise to new hypotheses on its structure.

Agenda for computer science in PA

What are consequences of the “Practical Impact Debate” for the interdisciplinary research field of computer science in sports? It becomes clear that there are different agendas for it working in either TPA or PPA. Nevertheless, both areas depend on data on the matches meaning that there remains a general agenda including the detection of positions and actions. The automatization of action detection will be a prominent future task as well as drawing inferences on higher level from action and position data, like analysing constructs not available before like availability or more complex tactical behaviours like passing style or pressing. Specifically for TPA the introduction of more appropriate models will determine a future

agenda. As interaction and dynamics are constitutive for game sports these features should be included in any future approach. What PPA is concerned challenges lie in improving informational service for coaches and athletes. We will see information systems that combine the different sources of information by machine learning technologies to arrive at advanced versions of automated data mining, for example driven by assumptions on the nature of information needed and driven by query habits of the user. All in all, there is a challenging but also promising future for computer science in PA to be expected.

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3.3 Performance Analysis in Soccer Based on Knowledge Discovery Approach

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Joint work of Leser, Roland; Moser, Bernhard; Hoch, Thomas; Baca, Arnold

The contribution addresses the development of explanation models for key performance indices extracted from position and tracking data. The goal is to come up with an explanation rather than a black box model which allows the explanation of the performance by means of behavioral patterns. For this purpose, a knowledge discovery approach for extracting behavioral patterns from position measurement data in small-sided soccer games is outlined. The resulting kinematic feature space of spatial-temporal variables is high-dimensional. In order to maintain interpretability for coaches, therefore, the reduction to a reasonable amount of variables is needed. To this end, the Laplacian Score method is introduced which yields promising results. This method aims at reducing the dimensionality while keeping the structure of the data. In a further step clusters in this reduced feature space are induced by taking key performance indicators into account. Promisingly, for small-sided games this

approach leads to expressive linguistically interpretable explanation models. Our contribution aims at discussing the potential of this approach also for more complex scenarios.

3.4 Individual Ball Possession in Soccer

Daniel Link (TU München, DE)

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This paper describes models for detecting individual and team ball possession in soccer based on position data. The types of ball possession are classified as Individual Ball Possession (IBP), Individual Ball Action (IBA), Individual Ball Control (IBC), Team Ball Possession (TBP), Team Ball Control (TBC) und Team Playmaking (TPM) according to the type of ball control involved. The machine learning approach used is able to determine how long the ball spends in the sphere of influence of a player based on the distance between the players and the ball together with their direction of motion, speed and the acceleration of the ball. The degree of ball control exhibited during this phase is classified based on the spatio-temporal configuration of the player controlling the ball, the ball itself and opposing players using a Bayesian network. The evaluation and illustrative application of this approach uses data taken from a game in a top European league. When applied to error-corrected raw data, the algorithm showed an accuracy of 92 % (IBA), 86 % (IBP), and 92 % (IBC) using a tolerance of 0.6 s. This is well above the accuracy achieved manually by the competition information providers of 52 % (TBC). There were 1291 phases involving ball control (IBC) totalling 29:39 min with a gross game time of 90:12 min and a net game time of 57:56 min. This initial analysis of ball possession at the player level indicates IBC times of between 0:22 and 3:18 min. The shortest ball control times are observed for the centre forwards of each team (0.9 s) and the full backs of the losing team (0.7 s) and the longest for the losing team's goalkeeper (2.9 s). This can be interpreted as a tendency for the defenders to try and clear the ball as quickly as possible and the goalkeeper attempting to slow the pace of game.

3.5 Understanding Actions in a Sports Context

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Understanding human action is critical to surveillance, monitoring, and situation understanding. Sports present events where the types of actions are limited and depend on roles, locations, and situations. Understanding the actions, activity and performance of the players interests many. Action understanding in broadcast video has led to progress in tracking, recognition, camera rectification, pose, and multi-view action recognition.

3.6 Performance Analysis in Soccer Based on Knowledge Discovery Approach

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The contribution addresses the development of explanation models for key performance indices extracted from position and tracking data. The goal is to come up with an explanation rather than a black box model which allows the explanation of the performance by means of behavioral patterns. For this purpose, a knowledge discovery approach for extracting behavioral patterns from position measurement data in small-sided soccer games is outlined. The resulting kinematic feature space of spatial-temporal variables is high-dimensional. In order to maintain interpretability for coaches, therefore, the reduction to a reasonable amount of variables is needed. To this end, the Laplacian Score method is introduced which yields promising results. This method aims at reducing the dimensionality while keeping the structure of the data. In a further step clusters in this reduced feature space are induced by taking key performance indicators into account. Promisingly, for small-sided games this approach leads to expressive linguistically interpretable explanation models. Our contribution aims at discussing the potential of this approach also for more complex scenarios.

3.7 Covered Distances of Handball Players Obtained by an Automatic Tracking Method

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Joint work of Russomanno, Tiago Guedes; Misuta, Milton Shoit; Menezes, Rafael Pombo; Brandão, Bruno Cedraz; Figueroa, Pascual Jovino; Leite, Neucimar Jeronimo; Goldenstein, Siome Klein; Barros, Ricardo Machado Leite

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Tracking players in sports events is still a topic of discussion in sport science and the data provided by this tracking is useful for team staff to evaluate team performance. Therefore, the aim of this work was to obtain the distances covered by handball players and their velocities during a match using a new approach based on automatic tracking method described in Figueroa et. al. [1, 2] and the Adaboost detector [5]. A whole game of a Brazilian regional handball championship for players under age of 21 was recorded. Applying the mentioned automatic tracking, the accumulated covered distances and the velocities were calculated for all the players. The results of average covered distances (\pm SD) in the 1st and 2nd halves were 2199 (\pm 230) and 2453 (\pm 214). The results of covered distances and the velocities allow individual and collective analyses of the players by the team staff. The proposed method revealed to be a powerful tool to improve physical analysis of the handball players.

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3.8 Data Requirements in the Sports Data Industry

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Different markets do have different requirements concerning data depth, data delivery speed and data quality. Here is a short overview about three markets: (1) Professional Sports, (2) Media, and (3) Bookmakers / Betting.

1. Professional Sports (Teams, Clubs, Leagues)
 - Strong need for deep data
 - Delivery speed not too important, as most teams use the data post-match. Moreover, live-match analyses are sometimes prohibited.
 - Data quality is important. Performance analysis based on imprecise data could cause wrong conclusions.
2. Media
 - Strong need for deep data (e.g. for story telling)
 - Delivery speed Not too important as there is a broadcasting latency anyways
 - Data quality is not important.
3. Bookmakers / Betting
 - Data depth is not important, as there is a market limit anyways. If you would offer too many bets, you would cannibalize your own market.
 - Delivery speed is a must have and very important
 - Just as data quality is. Wrong data could cause a of lot trouble and punters would claim their right to get their money back

Consequently, for a company like Sportradar it is very important to fulfill all different requirements. This results in the claim to be able to provide fast, highly accurate, and deep data.

3.9 Factors that Influence Scoring Dynamics in Low-Scoring and High-Scoring Team Games

Anna Volossovitch (University of Lisbon, PT)

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Joint work of Volossovitch, Anna; Pratas, José; Dumangane, Montezuma; Rosati, Nicoletta
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Research in match analysis frequently attempts to establish causal relationships between isolated performance variables and goal scoring or game outcome. This approach reduces the complexity of performance by presenting it in overly descriptive and regular ways, which do not reflect properly the curse of the game. The purpose of the presentation was to discuss two examples of the analysis of factors, which could influence the scoring dynamic during a match in handball and in football. In the first example, the influence of teams past performance on the present teams performance was evaluated throughout the handball match using the model with time-varying parameters. This model estimates the probability of scoring as a function of the past performance of the opposing team and the current match result. This assessment considers the specific context of the game situation, the teams rankings, the match equilibrium and the number of ball possessions per match. In the second example the performance indicators, which had a significant effect on the time of the first goal scoring in football has been identified using Cox time-dependent proportional hazard model. The survival analysis is suggested to be a suitable tool to identify which and how performance indicators influence the time of the first ball is scored in different competitive context.

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4 Overview of Talks: Sport Movement

4.1 Predicting Human Responses to Environmental Changes

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Joint work of Dorschky, Eva; van den Bogert, Antonie J.; Schlarb, Heiko; Eskofier, Björn
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Predicting human responses to environmental changes is necessary for biomechanical analysis and sports product design. If case studies, environmental conditions or prototypes cannot be realized, modeling and simulation can be used instead. The aim of this work was to evaluate a method of predictive musculoskeletal simulation [1] for uphill and downhill running. A

study was simulated by randomizing the model's muscle parameters. The predicted energy costs for running at different slopes were compared to literature [2]. Future work includes a personalization of biomechanical models to represent individual athletes as well as population groups. The sensitivity of simulation results to model parameters will be studied to ensure robust simulation results.

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4.2 Wearable Computing Systems for Recreational and Elite Sports

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Wearable computing systems play an increasingly important role in recreational and elite sports. They comprise of two important parts. The first are sensors embedded into clothes and equipment that are used for physiological (ECG, EMG) and biomechanical (accelerometer, gyroscope) data recording. The second are signal processing and data mining algorithms implemented on wearable computers (smartphones, watches) that are used for analysis of the recorded data. Wearable computing systems can provide support, real-time feedback and coaching advice to sportsmen of all performance levels. In order to implement these systems, several challenges have to be addressed. Our work focusses on four of the most prevalent of these:

- Integration: sensors and microprocessors have to be embedded unobtrusively and have to record a variety of signals.
- Communication: sensors and microprocessors have to communicate in body-area-networks in a secure, safe and energy-saving manner.
- Interpretation: physiological and biomechanical data have to be interpreted using signal processing and machine learning methods.
- Simulation and modeling: understanding of sensor data is needed to model processes in sports more accurately, simulation methodologies help here to provide basic information to drive those models.

4.3 What is the Right Model?


Karen Roemer (Central Washington University – Ellensburg, US)

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Investigating human movements requires using biomechanical models to perform kinematic and kinetic analyses. Depending on the available motion analysis system or software packages, anthropometric models, tracking models, joint models etc. are applied to quantify kinematic and kinetic variables. Two standard biomechanical models (OpenSim and Visual3D) were used to analyze a simple stepping task. Similarities and differences of kinematic and kinetic results for both models were discussed.

4.4 Model-Based Tracking of Human Motion

Antonie van den Bogert (Cleveland State University – Cleveland, US)

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Two sensing modalities are in use for field studies of human movement: inertial sensing and video. While both are suitable for analysis of human movement during sports events, data quality is usually far inferior to those encountered during laboratory conditions. Inspired by the classical Kalman filtering concept, we consider using a dynamic model to improve the estimates of the state trajectory of the system. This approach presents the estimation problem as an optimal control problem: find state and control trajectories that satisfy system dynamics and minimize a cost function. For tracking of sensor data, the cost function consists of the sum of squared errors between simulated and measured sensor signals. When using a musculoskeletal model, an extra term, representing muscular effort, must be added to ensure a unique solution. This is due to the classical load sharing redundancy: humans have more muscles than strictly necessary to produce movement.

Efficient solution methods have been developed to solve this optimal control problem, and the approach was successfully used to obtain a detailed analysis of a landing movement during skiing, based on low-quality video data [1]. The same approach was used to perform a full dynamic gait analysis, including muscle force estimation, with body-mounted accelerometers [2]. The accelerometer-based analysis was not good enough for clinical applications, because it was too sensitive to the unmodeled dynamics (damped vibrations) of the accelerometer attachments. Improvement is expected when the instrumentation is supplemented by gyroscopic angular velocity sensors.

Model-based state estimation will reduce the sensitivity to measurement error, and there are additional advantages. The estimation process includes estimation of the full state of the system, including variables such as muscle forces which could not be directly obtained from sensor signals. The raw data is then not only filtered, but also enriched by the dynamic model. A second advantage is that a dynamically consistent simulation is obtained as an additional result. Such simulations can be useful to explore “what if” scenarios, such as sports injuries that are caused by unfavorable landing postures [3].

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5 Overview of Talks: Adaptions to Training

5.1 Modelling Speed-HR Relation using PerPot

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Joint work of Endler, Stefan; Perl, Jürgen

Main reference S. Endler, J. Perl, “Optimizing practice and competition in marathon running by means of the meta-model”, in Proc. of 2012 pre-Olympic Congress on Sports Science and Computer Science in Sport (IACSS’12), pp. 127–131, World Academic Union, 2012.

A model, which represents the heart rate (HR) process based on a speed process has to model three aspects:

1. Increasing HR after increasing speed.
2. Decreasing HR after decreasing speed.
3. Break down after exhaustion.

The performance potential metamodell (PerPot) models all these behaviors. It was adapted to the environment of endurance running. Once, the model is calibrated to the individual athlete by a graded incremental test, it can be used for simulation of e.g. competitions. Simulations can help unexperienced athletes particularly to avoid overloading and underperforming.

5.2 Performance Adaptions to Football Training: Is More Always Better?

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Joint work of Folgado, Hugo; Sampaio, Jaime

Traditionally, performance in sports is measured by magnitude based indicators, summed up by the Olympic motto – Citius, Altius Fortius – Faster, Higher, Stronger. However, in several sport domains, and particularly in team sports, this idea has been challenged by recent research. In football, the physical analysis of matches in different competitive leagues have showed that players in higher level contexts tend to run less and at lower intensities than players involved in lower leagues [1]. In other approach studying the effects of congested fixtures in players physical performance showed no differences in the amount of distance covered and distance covered at different displacement intensities [2]. So, it may be speculated that the amount of displacement is not related to greater levels of performance in football. Based in these approaches, we measured players physical and tactical performance development during the preseason, evaluated during sided-games. Our results showed that players tend to reduce the amount of distance covered during these situation has the preseason

progresses. However, their tactical performance, measured as the amount of time players are displacing in synchronized manner, was higher as the preseason progressed. These findings lead to a need for shifting to a more holistic approach, where performance indicators need to be understood within the different interpersonal relations established during the match.

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5.3 Modeling Individual HR Dynamics to the Change of Load

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The success of training in sports and, in particular, in the application of Exergames, is dependent on setting an appropriate training load. Modeling the individual HR dynamics to the change of load in the sub maximal range provides an effective and efficient prediction of the individual strain in the human body. This enables systematic load control and is essential for an individually optimal training. This task is not simple. Beside the final steady state HR corresponding to the load, the slope of the curve is also essential for a reliable modeling. However, research has shown that this slope can vary in humans, depending on a great amount of influencing factors, i.e. age, body weight, sex, training and resting level and many more. Additionally, it can also vary in the same human under apparently similar conditions. Further research is needed to improve the modeling of HR dynamics inside Exergames:

1. Additional influencing factors on the HR, i.e. emotion or diseases, need to be identified.
2. Additional load on the human body caused by game control, i.e. body movements, need to be identified and controlled.
3. The formula for modeling the human HR responses need to be improvement and dynamically adapted.

5.4 Model Design and Validation for Oxygen Dynamics

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Joint work of Artiga Gonzalez, A.; Bertschinger, R.; Brosda, F.; Dahmen, T.; Thumm, P.; Saupe, D.
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URL <https://www.uni-konstanz.de/mmsp/pubsys/publishedFiles/ArBeBr15.pdf>

Measurements of oxygen uptake and blood lactate content are central to methods for assessment of physical fitness and endurance capabilities in athletes. Two important parameters extracted from such data of incremental exercise tests are the maximal oxygen uptake and the critical power. A commonly accepted model of the dynamics of oxygen uptake during exercise at constant work rate comprises a constant baseline oxygen uptake, an exponential fast component, and another exponential slow component for heavy and severe work rates. We generalized this model to variable load protocols by differential equations that naturally correspond to the standard model for constant work rate. This provides the means for prediction of oxygen uptake response to variable load profiles including phases of recovery. The model parameters were fitted for individual subjects from a cycle ergometer test. The model predictions were validated by data collected in separate tests. Our findings indicate that oxygen kinetics for variable exercise load can be predicted using the generalized mathematical standard model, however, with an overestimation of the slow component. Such models allow for applications in the field where the constant work rate assumption generally is not valid.

6 Comments

6.1 Research Perspective


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The Dagstuhl seminar was a very interesting and inspiring event for me. There were many opportunities and a good environment to discuss research. I would recommend to keep talks short also in future events to encourage this even more. Also, the different disciplines that were brought together was insightful, as well as the different backgrounds of the participants. It showed in what ways human modelling could be used in other fields of research and also how this could be helpful in commercial applications. A lot of work is still to be done before this can happen, for example in personalization of models for specific sports or even specific athletes.

6.2 Industry Perspective

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For a company it is very important to know about the latest research activities. The Dagstuhl seminar is a great opportunity to get the latest insights and discuss with prestigious representatives from different areas. Besides the important fact to extend the network it can result in concrete research collaborations and even in funded projects. I highly recommend to open Dagstuhl even more towards the industry, as science needs to be applied in concrete projects or products. Moreover, knowing about the requirements of the industry can also help scientists and universities to improve their research programs.

7 Discussion

In the seminar, the term “model” was not exactly defined to allow for a broad discussion. During the discussions, a different understanding of “models” became apparent depending on the background of each participant. In sport science, models are used to understand and predict the behaviour of e.g. sport games, human movement or physical performance of athletes. Models are commonly physically motivated and based on specialist knowledge. However, such models reach their limits when the underlying process is complex and the real world cannot be adequately represented. In machine learning, a model refers to an algorithm describing the dependency of input and output variables. Models are commonly data-driven rather than physics-based. Their application as black boxes conceals risks: How do we know that the results are accurate? How can we optimize our results? What causes problems? How to interpret the model structure physically? As a result from the seminar, computer scientist should provide more support and expertise to allow for insights into the behaviour of the model. Contrarily, the model structure depends on the chosen input and output variables. Therefore, it is essential that sports scientists and industry provide useful information: What are meaningful performance indicators i.e., model input, related to the problem? What output variables are of interest, e.g. to give useful feedback to a coach or the athlete?

In the seminar, the term “sensemaking” was mentioned in this context. As the amount of collected data is increasing, machine learning methods like unsupervised learning, offer new opportunities for joint collaboration. The combination of knowledge-based and data-driven models would be another advance. For example, position data of players during sport games is already available using computer vision or local positioning technologies. The position data itself might not offer enough insight to the course of the game. In terms of “sensemaking”, a pose estimation of the players would lead to a better behavioral understanding of the athletes. This could be done by tracking a biomechanical model with recorded video or inertial sensor data. Moreover, physical models, like biomechanical models, could be used to synthesise training data for training neural networks to improve activity recognition based on noisy sensor data. Finally, new methodologies like agent-based modelling and simulation should be applied to sports related problems. This implies a close cooperation between computer and sports scientists.

8 Conclusion

The seminar enabled fruitful interdisciplinary discussions concerning the core problems of modeling and simulation starting with the acquisition and preprocessing of data, the selection of the appropriate model(s) and ending with the verification and validation of models. The seminar also uncovered the different perspectives of science, practice and industry on modeling and simulation as well as the necessity of all parties to communicate about their views and mutual expectations. Furthermore, the discussions revealed the ambivalence of applying ICT to modeling and simulations in sports. On the one hand, added values like accuracy, speed, and complexity as well as convenience were emphasized. On the other hand, numerous issues including error identification and correction in the data, data quality in general, classification problems, and knowledge discovery in “big data” were addressed. Due to the “spirit of Dagstuhl” the schedule was finalized and flexibly adapted during the seminar. Some guidelines were suggested to the presenters to establish overarching aspects for discussion, e.g., how models were selected and applied to the problem at hand and which advantages and disadvantages appeared in the process of modeling.

There was a broad agreement that the series of Dagstuhl seminars on computer science in sport should be continued. The positive results of the seminar evaluation confirmed the high quality of the seminar. However, some things need to be improved concerning the structure of the seminar as well as the commitment of the participants, e.g., talks more structured and focused on fundamental issues rather than specific aspects, fostering more discussions by shortening the talks as well as a better preparation of the seminar by collecting main topics in advance (e.g., three basic issues per participant). The organizers are sure that the next Dagstuhl seminar will be successful in improving the quality beyond the high level already established by this seminar.

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