# Coaching and computer science

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## Abstract

Coaching is one of the earliest areas of application of computer science in sports. It may be divided into three different activities – preparation, control and debriefing of competition. These stages create different conditions for the support of coaching by computer science with the stage of competition control being most demanding, because data acquisition, data processing and data-based interventions have to take place during and at the site of the competition.

The history of computer science and coaching was marked by continuous technological progress and growing conceptual insights into the process of coaching. Although there is considerable support in processing observational data including video data, it has to be acknowledged that central activities of coaching are not affected yet, e.g. analyses of strengths and weaknesses or the central task of strategy development and implementation. Conceptual advice for these tasks of coaching is obtained by qualitative research methodology, e.g. for assessment and intervention. Nevertheless, there are excellent perspectives for coaching and computer science. Real-time position analysis (RTPA) will allow support during competition. Analyses on more abstract levels than just positions will become possible using methods of artificial intelligence. This will result in new options with unforeseeable impact on the work of coaches.

## 1 Introduction

Coaching is one of the earliest areas of application of computer science in sports. Especially in game sports analysis tools from computer science were introduced very early, that means almost as soon as they were technologically available. Interestingly enough, in the 1970s parallel developments occurred in different countries dealing with the same problems without knowing about each other [1, 12, 24].

The situation has improved a lot since the founding of the International Association of Computer Science in Sport (IACSS) in 2003 that organizes biannual meetings for the exchange of knowledge and recent developments in this area. Still, applications from the area of coaching make up many of the contributions to these conferences and to the International Journal of Computer Science in Sports (IJCSS).

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The reason for the attractiveness of computer science to sports coaches is simple. Imagine a football game with 22 players going on for 90 minutes. As almost any action is of relevance for coaching, acquisition and data processing of behaviour in football deal with an overwhelming number of behavioural items during a match. In fact, satisfying observational systems in many sports have only become possible through the aid of computer science.

Although pointed out already 30 years ago, some of the aims of introducing computer science into coaching are still far from being achieved. There are different reasons for this. First of all, there was too much optimism concerning the impact of computer science developments into sports practice. The willingness of practice to adopt computer science technology into their daily work, but also the capabilities of computer science in these early times were largely overestimated. The nature of the problems in the coaching process was not well understood, especially the fact that coaching comprises activities that are only to be supported by computer science if severe problems of artificial intelligence are solved. The solution of these problems has come within the reach of computer science only recently. Finally, there was large-scale failure in supporting coaching by computer science simply because one didn't know how to conduct a scientific intervention in sports practice appropriately. In some of these areas there has been much progress in recent years. Especially technological developments allow us nowadays to think about projects that are actually able to realize the 30-year-old dreams.

This chapter starts with some remarks on the process of coaching. It makes clear the requirements for giving support in this area. After that the technological standards for preparing and analysing a competition are outlined. The final paragraph glances into the future and describes the state-of-the-art and possible developments in real-time analysis of sports, which supplies coaches with tactical and strategic hints during a game.

## 2 Coaching

This paragraph starts with a definition of what we want to understand exactly by coaching. After this, coaching is divided into three different activities – preparation, control and debriefing of competition. These activities are analysed with respect to the demands they pose to support by computer science. As it is difficult to describe the potential impact of computer science to coaching for every sport and every group of sports, most examples used come from team sports like football, volleyball and basketball. Things may be quite different in other sports, and the arguments lined up here have to be carefully transformed to further areas of application.

### 2.1 Definition of coaching

*Coaching comprises all activities in training that are directly related to a special competition.* These activities may occur before, during or after a competition and are termed preparation, control and debriefing of competition, respectively. By *training* we mean coaching as well as all the other activities not related directly to a special competition [10].

This definition of coaching differs a little bit from its meaning in English or American, where coaching is a more comprehensive term. The advantage is that we are now able to distinguish between more long-term oriented or routine measures and those related to a special competition. To make it clear, coaching activities are considered of being a subset of training activities.

What are those activities in coaching? Because we have basically a short-term range for the measures, we find activities predominantly where we can induce changes on a short-term range. That means we are, for example, talking about cognitive aims like a game strategy. We try to build up an appropriate mental attitude towards the competition, and we have the big issue of motivation which is considered to be very essential by many people. To a lesser extent we find physical adaptations as the aim of coaching because in general this takes longer periods than available for coaching.

It is short-sighted to assume that the support by computer science contributes only to cognitive aspects of coaching, e.g. developing and implementing a winning strategy. There are good reasons to assume that a proper support in this area, an elaborate and well-founded game strategy obtained with the help of up-to-date technology strongly exhibit an influence on motivational and psychological aspects. Up to now this assumption remains hypothetical, though, unless some research is conducted to enlighten that interesting question.

### 2.2 A conceptual framework for coaching

Although we want to restrict the reach of the term ‘coaching’ to a narrower field of activities in training related to a special competition, it is useful to distinguish different stages in coaching. Especially, the role of computer science is different in those phases. This point will be discussed after a brief introduction of the three stages.

Figure 1 shows the three stages of coaching we want to distinguish. The criterion applied is simply the temporal position of the activities relative to the competition one is preparing for. Coaching activities before competition are called preparation of competition, those during a competition are termed competition control and all coaching activities after a competition belong to the stage of competition debriefing. What are the specific aims, what are the typical settings of these three stages?

The *preparation for a special competition* is the first task in coaching. The big issue in this phase is the competition strategy, i.e. an action plan based on an analysis of my own team and the opponent with the aim of maximizing success in the upcoming competition. We may distinguish two phases in this stage of coaching. The strategy has at first to be developed by the coach and then the athletes have to be trained to be able to execute it. This in turn requires a cognitive and

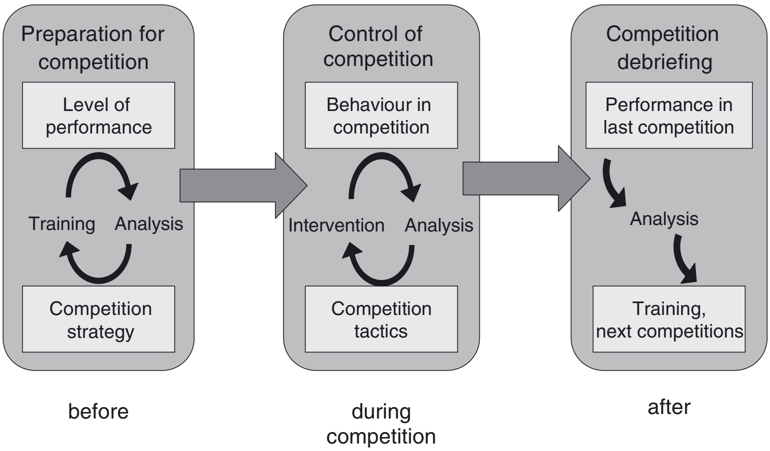


Figure 1: Stages of coaching [10].

eventually a motor learning process simulating decision behaviour in situations the competition strategy is referring to.

Of course we find deviations from the classical roles of the coach and the athlete. Especially in individual sports athletes are also engaged in strategy development and not just passively receiving the instructions of the coach. The setting in this phase is typically the regular setting of a training session. In general, there is enough time to complete the tasks of this phase, unless we have a tournament with a tight series of matches. In beach-volleyball, for example, the typical World-Cup tournaments require several matches per day, which makes it very difficult to extensively develop a strategy and to teach it thoroughly to the athletes.

*Control of competition* is the task of the coach during the event. The coach observes permanently the game regarding two aspects: Is our competition strategy in effect, i.e. has it become our competition tactics, and is there success or failure of my team? In case of undesired deviations from competition strategy the coach tries to re-establish it. In case of success the coach reinforces the perceived causes of success. In case of failure the measures against the perceived causes are to be taken. The longer the match lasts, the more likely deviations from the initial strategy occur.

Two basic problems arise at this stage of coaching. First, we frequently find limits of the coach's ability to realize reasons for undesired behaviour during the match. This is partly due to the fact that the observation does not cease while reasoning. Second, even if appropriate measures are identified, there are limits to a successful intervention. It is difficult to transfer the necessary information to all the players, especially if there are basic changes required.

The latter problem depends largely on the rules of a specific sport. In many sports the rules provide 'natural' opportunities for an intervention like breaks between periods of a match. Two, three, four or nine periods are some well-known examples. In some game sports the coach may take time-outs that provide, of course, excellent opportunities for changing or reinforcing the competition strategy. The replacement of players is another measure to influence the match that is controlled by the rules. Finally, the rules specify the communication between the coach and the players during a match what is of course important for the ability of the coach to exhibit control. These considerations make it clear that the conditions to exhibit control during a match are excellent in some sports, e.g. American football, and not existent in others, e.g. swimming. Here, it may be speculated that the coincidence of opportunities for coaching during a competition with opportunities for placing advertisements during its broadcasts have led to excellent conditions for coaching in the United States' big four: American football, baseball, ice-hockey and basketball.

The setting in this stage of coaching is of course the competition itself. Observation, analysis and communication are processes that run parallel to the competition and have to be performed at its location.

In *competition debriefing* the last performance is analysed in depth and reasons for success or failure are identified. Another important item of analysis on this stage is whether or not the chosen strategy was appropriate.

The results of these analyses are used as cognitive or motivational feedback for the players. They are also a valuable input for short-term planning of the next periods of training, if the analysis has detected important targets that may be addressed by a short-term training intervention. Targets for long-term training may be collected and aggregated over several analyses. The critical analysis of the chosen strategy is part of the coach's learning process on that meta-level.

The setting for the feedback is typically the next training session. Also, at this point in time the short-term consequences of the analysis for the training process have to be known. The analyses may be performed at any place available in time to meet these demands.

### 2.3 Conditions for support by computer science

In general, the setting of the *preparation stage* exhibits hardly any restrictions to the use of technical support for the analyses. We may work at the usual analysing facilities; we may conduct in-depth analyses of the next opponent without too much pressure of time. Results have to be present before the last few training sessions in order to teach the competition strategy to the players. Of course, it is necessary to schedule sessions between the head coach and the staff responsible for performance analysis.

It must be mentioned though, that these nearly ideal conditions cannot be met in certain settings, e.g. in tournaments of net/wall games where we typically have a high density of matches (daily or even several matches a day) and we get to know the next opponent only comparatively late. This makes it difficult to clear all the tasks of this stage in time, a fact which is not compensated by the availability of up-to-date information on our opponent.

The setting of *competition control* imposes strict limitations to support given by computer science. The aim is to give the coach some advice for his decisions of how to influence the match. As these decisions have to be ready at the intervention points, the supporting information has to be available prior to these interventions. We are forced not only to execute data acquisition and data analysis in parallel during the match but also to present these analyses in a useful fashion to the coach whenever he needs it.

Moreover, in addition to these strict temporal limitations we face the problem that support has to be organized at the location of the competition. This may cause severe problems in away matches with restricted access to the competition site. Also, making videos of sports events has become a juridical problem in the last years. The task is also to establish a reliable communication network between observers – usually several ones distributed over the location, the game analysis coach and the head coach.

In the stage of *competition debriefing* we may in general work again at our usual analysing facilities. It is important to note though, that information is needed as soon as possible after a match, because feedback should be given as early as possible to the players, ideally in the next regular training session after competition. A professional staff is required to meet these demands reliably especially when analyses are very time-consuming.

The purpose of this chapter was to introduce the different stages of coaching in order to make clear the different tasks of the respective stage and the temporal and local restrictions we may face if we want to support the coach in these stages. It has been shown that requirements differ largely among these stages. The next chapters present the state-of-the-art and perspectives of computer science to give support for the respective stages of coaching.

## 3 Computer science and coaching: history and state-of-the-art

Computer science and coaching is a typical interdisciplinary research area. It has been subject to considerable progress due to technological developments in computer science. On the other hand, sports science has the task of observing the technological progress and considering whether new desirable applications are accessible. If this is the case, true interdisciplinary work starts by analysing the problem and looking for a structure that allows the task to be solved with the help of new developments.

In this chapter the most important technological developments in the past are examined with regard to their impact on coaching. From the view of sports science, the structure of classical observational systems is analysed and recent insights and the state-of-the-art of the methodology of game analysis are reported.

### 3.1 Technological developments

One of the most outstanding characteristics of computer science is its enormous progress in hardware developments. Perl (2006) examines the last 10 years and observes increases in processing speed of about a factor of 30 and even a factor of 50 for main storage devices. These quantitative developments result in different qualities, too. User interfaces, multimedia and communication have changed dramatically in the last decade. On the other hand this was achieved by an increasing complexity of software architecture which makes software development the exclusive task of professionals.

What were the most important developments for coaching? The very first applications of computers in game analysis made only use of the data processing capabilities of computers. As still present in the French 'ordinateur' for computer, one was able to get lists sorted for many aspects basically from data gathered by hand notation. If one records for example point of time, player and action, three lists sorted by these variables provide specific analyses. Even being rather primitive, these analyses are pretty difficult without the help of a computer. So, we have a first phase of computerized observational systems in sport that is dealing with transferring hand notation systems to the computer.

The next phase is characterized by efforts to optimize the interface between observer and computer. In the eighties QWERTY-keyboards were partially replaced by digitization pads. These are electronic devices that allow to point with a digit to a spot on the pad and record the coordinates of this contact. By defining areas on the pad according to the categories of the underlying observational system, one was able to enter observational data much faster than before. New qualities of analysis were also achieved by this new technology, because it also allowed to record positions of ball and players by transferring positional observations to a pitch laid out on the digitization pad [4].

Another development aiming at the facilitation of data entry is the voice detection [26, 20, 19]. The idea is to transfer spoken comments to the categories of an observational system. Although there were some early efforts, the potential of this technology has not been exploited to its full extent. Especially considering the present progress, making it for example possible to direct traffic positioning systems by the voice of the driver, gives reason to assume that just a severe effort is lacking that makes voice detection a valuable tool for observational analyses in sports.

Another phase of development was achieved when it became possible to control video by computers [27, 6]. These early multimedia applications were most important for coaching and game analysis because video is the most common medium to document sports. Again, a hardware development – new interfaces between computers and video – allowed to introduce new solutions to problems of sports practice. Feedback given as a result of performance analysis could be presented using video, the most widespread medium in sports. Above all, the content of feedback could be selected by the medium responsible for the analyses, the computer. It has to be mentioned though, that a practical impact in a broader sense took place only with the transition from analogue to digital video in the late nineties, which is again due to the increased data processing and data storing capacities. This phase represents the state-of-the-art of common observational systems at present.

Figure 2: Information technology for game observation.

Another line of development has to be mentioned. Together with the astounding increases in capacity there was a considerable decrease in physical size of information technology. This trend is especially important to applications in coaching, because we rely on mobile, easy-to-install and physically robust devices due to the scenarios mentioned above. In addition, a considerable reduction in costs is an interesting feature of computer technology. Since the introduction of personal computers in the early eighties computer industry aims more and more to sell its products to consumers rather than to professionals. This development has of course extremely facilitated the use of information technology in a field like coaching.

Figure 2 shows the technological equipment used to support coaching of the German national beach-volleyball team at Bondi Beach during the 2000 Olympics at Sydney (bronze medal). The observer occupies just the space of a regular spectator with a video camera and a laptop. Video is stored directly at the hard disk of the computer; the observer codes the beginning and the end of rallies and may enter first comments. The costs for his equipment were about 1500€.

## 3.2 Observational systems

Parallel to these developments in computer science that were gradually introduced in coaching we also find developments in sports science in the search for appropriate observational systems for analysing sports. These developments were

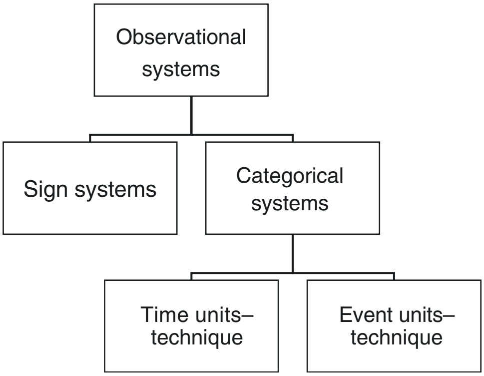


Figure 3: Strategies for designing observational systems [16].

inspired by the concept of model building which is also an important issue in computer science [3, 23].

From behavioural sciences we have learned about different strategies of how to build an observational system (see Figure 3). If we are interested in special events, we use a sign system. Here, we code every appearance of a certain, well-defined sign, e.g. a pass or a shot at goal. The result is a list with frequencies for all the signs we have specified beforehand. Alternatively, we are interested in the 'stream of behaviour'. In this case we have to specify a comprehensive categorical system with which we are able to describe the state of our behavioural system at any time. Within this strategy we have two techniques. One may structure the stream of behaviour temporarily in coding the state of a system for successive time intervals, e.g. code the state of a water polo game every five seconds [21] or one considers a game as a chain of events, e.g. service, reception, set, attack, block in volleyball. As a result of this strategy we are able to preserve the temporal structure of a match and may deal with questions relating to weak and strong phases of a game or frequent patterns of behaviour. In coaching we find very often that sign systems are preferred in practice, because this reflects much more the way a coach usually thinks about a game. The processual perspective is not so common, at least what demanded support by observational systems is concerned.

Together with the decision for an appropriate observational strategy the specification of the observational units like signs, a categorical system for time intervals or events may take place. In general we record several items per observational units, e.g. temporal and spatial items, technical and tactical descriptions and so on. The items may be continuous like positions on the pitch in metres or discrete like different service techniques in tennis or volleyball.

An early insight into the nature of observational systems was that such a system has to be considered as a model of the observed sport. Designing an observational system is very much a process of model building. This becomes evident when one looks at the reasons why we design observational systems and for which purpose they serve. We design them to represent the original, and their purpose is to draw inferences about essential properties of the sport. These are exactly the definitions of a model and model building [25].

Another insight arose only later. For some time in the past the leading opinion was that there should be one model for each sport. It was assumed that something like the observational system for tennis existed. Candidates for that universal tennis model became more and more comprehensive and sophisticated. They provided pages and pages of statistics as output for just a single game. At this stage it became obvious that observational systems have to be designed matching the purpose they serve. Different purposes, e.g. modelling the sport at an abstract level, examining a certain tactical behaviour, providing a detailed description of the game and last but not the least giving support in the coaching process, need different observational systems. An issue of model validation is not only whether the model is a good representation of the original, but also whether a model meets the purpose it was designed for.

At this point of theoretical considerations on observational systems in sports the question came into focus, what its special properties should be in order to meet the demands of coaching. The question can only be answered, if a concept of the coaching process is provided by sports science.

### 3.3 Coupling of competition and coaching

No matter within which stage of coaching one operates, a coupling of information between the game behaviour and the coaching process is required. The coupling of competition behaviour and coaching was proposed by Hansen and Lames [8, 15] to comprise a three-step process. Figure 4 presents this concept for the

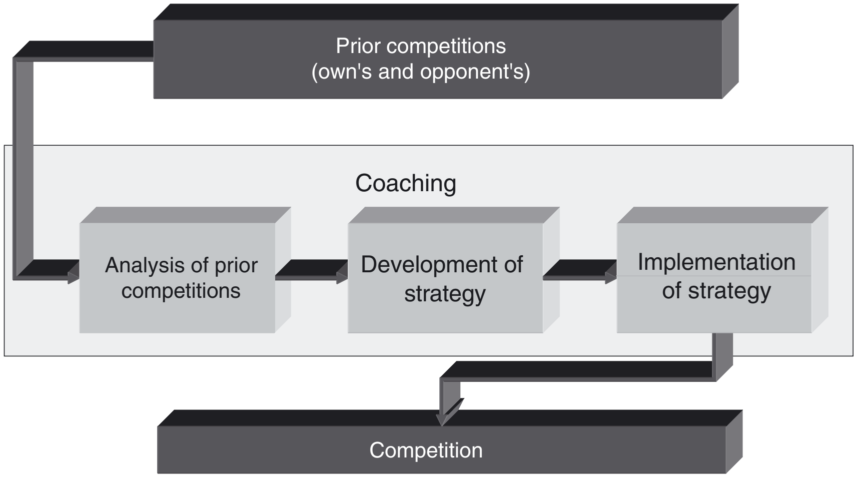


Figure 4: The three steps of coaching.

preparation of a competition. This concept holds with minor changes also for competition debriefing, when the input is our last competition and the coaching activities serve to improve our next ones. During competition the game to be analysed and affected is of course the ongoing game.

In the first step, a detailed description of prior competitions is required using an appropriate observational system. The quality of this description depends on the reliability of the observation process as defined in the narrower sense of measurement consistency. Its validity is determined by the degree it provides all the information required in the next steps of coaching.

In the second step, a strategy for the next competition has to be developed. The coach has to analyse the strengths and weaknesses of his own athletes and the skills of the opponent. The most ambitious part is to anticipate the interaction between the two sets of strengths and weaknesses. Important questions are: What is a typical behaviour of the opponent in a certain situation that might be exploited by my athlete? Which situations should be avoided, and how can this be achieved?

The third step, implementing the strategy, deals with the question of how to enable my athletes to apply my strategy in competition. The appropriate measures to be taken in training are derived from practical experiences, detailed knowledge about my athletes and the strategy to be instructed. One may not forget that strategies in sports usually do not only deal with cognitive problem solving, but perception, motor control and psychological aspects like volition and motivation are also deeply involved.

Structuring the coaching process into these three steps yields one basic insight, which is important for support intended by computer science. Coaching is by no means an algorithmic process that may be executed automatically according to a small set of simple rules operating on data from prior competitions. For example, while inferring from strengths and weaknesses of athletes one must consider many other factors such as the individual competition tactics and strategy, as well as situational aspects such as the psychological, physical and cognitive processes that occur during a game, the quality of the opponent and the level of preparation of the players. The interpretative rather than algorithmic nature of coaching becomes even clearer considering the step of strategy development. Anticipating the interaction between two opponents is highly speculative!

The consequences of these considerations are that up to now computer science has actually not been able to give much support to these central tasks of coaching. On the other hand, these tasks consist basically of cognitive, rule-driven operations. Coaches use tacit knowledge and soft rules from their experience in the domain to arrive at their decisions. It becomes evident that methods of artificial intelligence do have a big potential in this area. The development of an expert system on strategy development in coaching would pose an interesting challenge to artificial intelligence.

For the time being, the support computer science may provide is to facilitate the task of the coach. Most advanced coaching aids are designed to play their role in the three-step process cited above. Corresponding conceptual frameworks for practical performance analysis acknowledge the interpretative nature of the task.

### 3.4 Qualitative game analysis

The insight into the qualitative rather than algorithmic nature of coupling of competition behaviour and coaching has led some authors to apply the principles of qualitative research methodologies to this task. Qualitative research methodology exists in numerous variants, but has some features that make it well suited to practical performance analysis [5]. Such features include its applications in tackling practical problems rather than theoretical ones, its holistic and contextual approach to framing and addressing issues as opposed to the reductionist and analytic approach of quantitative methods, and its concepts of communication and intervention. Qualitative approaches adopt an interpretative and reconstructive view of social reality which is deemed appropriate for mastering the steps necessary for practical performance analysis as listed above.

To illustrate some of the characteristics of qualitative game analysis (QGA) we report in brief on an observational method that was designed to support top-level teams in beach volleyball. The details of this approach are documented in Refs. [8], [9] and [15] (see Figure 5).

The first part of QGA uses a quantitative observational system to identify the video scenes with regard to some specified items (e.g. service, reception, attack, result). This step is called quantitative pre-structuring and serves to prepare for the qualitative analysis to follow. Here, in contrast to many other purposes of observation, it has been proven to be useful to use a relatively rough grid of

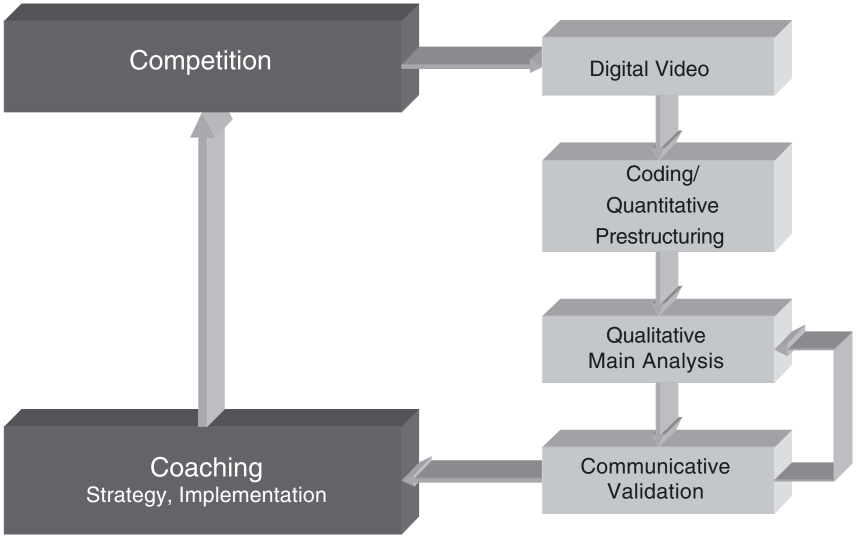


Figure 5: Steps of qualitative game analysis (QGA).

observational items. If this grid is too detailed, the search space would be unduly restricted.

In the qualitative analysis phase, the performance analyst examines the scenes selected from database retrieval using the parameters identified in the quantitative phase. These scenes may be rallies with striking features identified from a general statistical inspection (e.g. an unusual large number of service errors), or rallies containing important tactical behaviours that are looked for as a matter of routine (e.g. the service tactics of an opposing team). At the end of this step, the performance analyst will have developed a preliminary game strategy for use against the opponent just examined.

The last step of QGA is called communicative validation. In qualitative research methodology, it is typical that the scientist on one side and the participants on the other, in this instance the coaches and the players, communicate on equal terms. They enter into an iterative process, occasionally with additional support from video scenes that are displayed on demand. In the end an agreement on the final game strategy is reached.

Qualitative methodology provides advice for the central tasks of QGA. One idea is that the analysis of video scenes uses a method that is derived from content analysis, a common research method used in qualitative methodology [18]. Second, communicative validation is conceptualized as an iterative hermeneutic circle that is repeated until a common reconstruction of the findings emerges [7]. Finally, qualitative methodology provides a framework regarding how to conceptualize social interventions, which is appropriate when aiming at introducing changes in social systems.

Lames and Hansen (2001) reported a successful practical intervention with the German National Beach Volleyball teams at the 2000 Olympics at Sydney, Australia, using QGA as described. For three years one of the authors (Hansen) was involved in the preparation, the qualification and in the coaching itself during the Olympic tournament. The bronze medal was won, although the team did not finish better than 7th in the World Cup tournaments beforehand. Of course the authors do not claim that the intervention using QGA was the only cause for the German team's success.

At this point, one might ask why many examples of successful practical performance analysis worked in the past without the conceptual base of QGA. The answer is that every successful intervention has managed somehow to interpret observational data correctly, to communicate successfully with the coaches and players and to intervene efficiently in this special social context. It may be assumed that the principles of QGA were realized implicitly in these cases, a suggestion that is confirmed from talking with experienced game analysts. They report frequently that information has to be filtered prior to a presentation to the coaches, that there are long discussions with coaches on the meaning and consequences of the observational data, and that social acceptance of the information provided by the analyst to the coaches and players is paramount if it is to exhibit any influence on sports practice.

# 4 Computer science and coaching: perspectives

In this paragraph perspectives of future developments in the area of coaching and computer science are analysed. This is due to the fact that technology is right at the edge to allow sports and computer scientists to work with a new generation of tools to support coaching. The technology giving rise to these expectancies is RTPA. We are right at the edge to be able to track positions of players and ball, runners, drivers in real time, allowing for the first time in many sports to conduct supporting analyses during the event, a necessary condition to support coaching at the stage of competition control.

First, some technologies of RTPA are introduced and discussed. After this, the long way from automated position detection to coaching is described stressing the challenges for computer science that still remain. Finally, it is pointed out that such a system would immediately offer unprecedented options for performance analysis with unforeseeable impacts on coaching.

## 4.1 Real-time technologies

At present, RTPA is one of the hot spots of computer science in sports. There have been efforts using different technologies:

- *GPS*: This satellite-based technology uses radio waves and is very common in traffic-guiding in cars and trucks. The necessary spatial resolutions for sports purposes may only be achieved with additional equipment, though. Moreover, there must be a permanent visual contact between emitting and receiving stations, and the tracked objects have to wear small antennas. The technology is very well applicable in sports where athletes wear helmets and pursue rather simple trajectories in space such as cross-country and alpine-skiing or ski-jumping [13]. Although there was some disappointment in recent applications where the robustness of the measurements is concerned there are new promising fields of application such as rowing.
- *Radar*: RTPA-applications on the base of radar waves have demonstrated to be successful in motor sports [17]. There is almost no limitation on the number of tracked objects, the sampling frequency and the area to be covered. Systems are commercially available and have been successfully used to analyse for example the trajectory in speed skating even on indoor tracks. Radar technology requires the tracked objects to be equipped by active tags.
- *Microwaves*: Specialized on the demands of soccer, a research group has recently demonstrated the necessary basic capabilities of microwave technology for the purpose of real-time position tracking [11]. Practical tests in football were devoted to the control of the goal line to provide objective decisions on goal/no goal. The achieved precision was not fully satisfactory for this aim. Nevertheless this remains a promising technology, because for scientific purposes or for coaching a much lower precision may be tolerated. Microwave technology requires active tags for players and ball, too.

- *Image processing*: An unchallenged feature of RTPA by image processing is that the players and the ball need not to be equipped by any tags, which is a great advantage in terms of the necessary compliance of clubs and associations. Along with nowadays ubiquitous digital video, position detection by image processing came into the reach of users outside of computer science. In football, semi-automatic position tracking is commercially available and run regularly by leading European clubs.

As pointed out, the most promising technology for RTPA is image processing. Because either the rules have to be changed or the opponents have to show compliance, any technology requiring tags face severe problems of being installed in practice. Therefore, position detection by image processing is explained in greater detail.

In a first step the system is provided with some prior information, e.g. the coordinates of visible items in the field like the lines on a soccer pitch. Also, the system has to be trained to detect the colours of the teams and of the pitch. Position detection of an object consists of three steps:

1. In each frame, the projection of the 'world' into the pixel map is calculated by fitting its known coordinates to their pixel representation.
2. Pixel positions of players and ball are detected by image-processing techniques.
3. Applying the inverse of the projection of the world into the pixel map from step #1 to pixel positions of tracked objects yields the positions of these objects on the pitch.

Problems still persisting in the first step arise from the quality of video images. Unless there is a large number of fixed cameras covering all parts of the pitch we have to make sure that pixel resolutions of tracked objects are large enough, that swaying cameras do not cause too much blur in the colours, and that optical bias in the pixels by violations of linearity by camera lenses or curvature of pitch do not result in imprecise estimations of world's positions in the pixel plane. In the second step the length of the tracks of objects identified automatically depends on the 'cleverness' of the tracking algorithms. Simple colour matching hardly yields good results, especially in football, where we face frequently overlaying objects that make up 'blobs' consisting of two or more tracked objects. The last step is basically an algorithmic one and yields precise estimates for the pitch positions (error < 25 cm) if the prior steps worked reasonably well [2].

### 4.2 From position detection to coaching

This paragraph is intended to analyse the new offerings of RTPA with respect to the needs of coaching. In other words the question addressed is how much support may be expected by RTPA. The answer will be that coaches will of course profit from RTPA, but the most promising perspectives for coaching are only achievable, if inferences from the positional data are drawn on 'higher' e.g. more abstract levels like tactical behaviour, quality of actions and so on. This, in turn, poses additional challenges to computer science, especially in the area of artificial intelligence.

Let's first have a look at information made available to the coach by 'pure' RTPA, i.e. just by presenting positional data. We may just record the position of players and ball and depict it as a 'heatmap' like it is shown in Figure 6. Here the positions of two players of the German national women's football team are shown for the first half of the game. Immediately one gets an impression of the regular areas of operation of the players and special tasks like free kicks and corners. A very interesting option is to present the heatmaps dynamically, e.g. a heatmap-movie showing a 10 minute window over the match [14]. Heatmaps have of course been available for a long time, but only hours or days after the match. With RTPA the coach may inspect heatmaps continuously during the match and draw inferences for tactical changes from it.

Another option that may be realized immediately on the basis of positional data is to collect distances run and running intensities. Figure 7 compares Garefrekes and Lingor for their respective distribution of running intensities. One may notice considerable differences between the playmaker and the winger which are somewhat surprising. Having this information at hand any time during a match allows the coach to make assumptions on fatigue-levels of his players. Again, he can evaluate how their movement profile changed over the match. This gives important hints, for example, for the main coaching decision in football which players to replace. Moreover, as these profiles are available for the opponent's players also, this provides valuable information for tactical planning during a match.

Although these options promise great progress in the support of coaching, one still has to admit that they do not support the central tasks of it as pointed out in Figure 4. They do not help in identifying strengths and weaknesses of players; they do not supply suggestions for a game strategy. Intelligent processing of

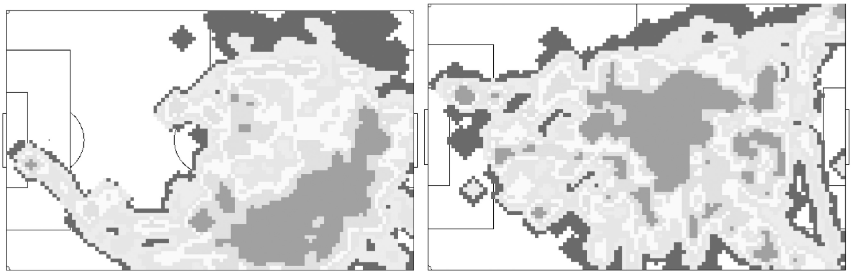

Figure 6: Heatmaps (distributions and frequencies of positions on pitch) for Garefrekes (left, forward mid-fielder/winger of German women's football national team) and Lingor (right, play maker, specialist for free kicks and corners) from a world-championships qualifying match against Switzerland in November 2005.

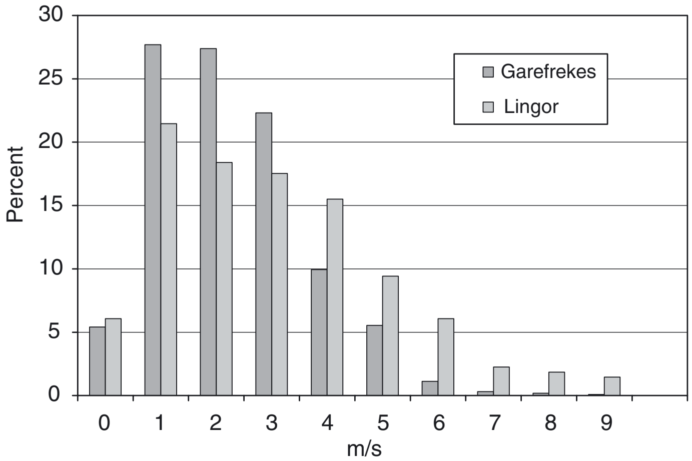


Figure 7: Comparison of distribution of running speed between Garefrekes and Lingor.


Figure 8: Levels of computerized analysis of a football match.

positional data alone does not at all exploit the potential of computer science to its full extent. We need inferences on higher levels than just the level of positional data. We should use techniques not only from image detection but from image understanding to proceed to analyses on higher levels (Figure 8).

First, positional data of players and ball could be used to identify actions on the pitch. Important concepts like ball possession, pass, dribbling or shot have to be detected by these means giving an overview of action profiles of players. Analyses on the level of actions are also valuable to estimate load and strain of players. For example, research has shown that energy expenditure is higher when moving with ball than without ball at the same velocity. A dribbling against a dogged defender consumes for sure more energy than walking with the same speed. These well-known facts mean that an estimation of the strain of players has to combine data from the positional and the action level.

With the actions on the pitch given one may infer on situations. These are tactical configurations like fast break, position play, screen pass or counter attack. But not only an analysis of the behaviour in the field according to a general classification may be obtained, but also individual analyses of situations may be given. That means for example the degree at which a situation poses a threat to the goal or an assessment of the value of different options to pass may be obtained at that level. This allows to evaluate the quality of tactical decisions of players during the match and maybe gives rise to corrections of the game strategy.

At still a higher level, tactical behaviour is analysed. This integrates in a way information about behaviour in certain situations and gives a comprehensive overview on the degree a player obeys to his tactical duties. Analyses are conducted that aim at revealing the opponent's tactical system in offence and defence. One may control the tactical discipline of players of one's own team.

Above all there is a level of assessment where comprehensive evaluations are realized operating directly on issues interesting to coaching. For example strengths and weaknesses of players in physical, technical and tactical sense, preferred operations of players and team, agreement between game strategy and behaviour of own team and opponent, changes in tactics after critical events in game such as disqualification of a player, change of players or goals marked.

So, there is no doubt that computer science has the potential to support coaching in a much broader and deeper sense than is realized uptil now. On the other hand, most of the above cited items require extensive research in the most challenging areas of AI: multi-agent systems, detection intention, image understanding and others. It is an important point to note that RTPA will unfold its full benefit for coaching, only if one proceeds to the higher levels of analysis cited above, because this is where the important decisions in coaching take place.

On the other hand, coaching provides to computer science an excellent opportunity to develop its capabilities in an area with a large public attention, a widespread knowledge of domain and a large number of people familiar with problems in the domain. This type of cooperation may become typical for interdisciplinary contacts between sports science and computer science.

### 4.3 Future perspectives

In this last paragraph three big issues are discussed that will most probably be the main concerns in the area of computer science and coaching in the near future. These issues constitute demanding challenges for both disciplines, for computer science as well as for sports science. They will account for much of the legitimation the interdisciplinary research area computer science in sports will be founded on.

*Pervasive computing and real-time analyses*: It is not implausible at all to expect great progress in the area of pervasive computing and, closely associated to that, real-time analyses in sports. Sensor technology, signal detection and evaluation software will allow for unprecedented developments in this area. Performance monitoring in sports will become ubiquitous. Maybe the main drive in this direction will not come from coaching but media is already and will even be more engaged in a race for the most spectacular presentation of sports.

The task for researchers in the area of computer science and coaching will not only be to realize the systems of information technology that realise technological innovations in the area of sports. They will also have to provide ideas and concepts of how to work in practice with these new tools. The new informational base and its unlimited availability will for sure make the practical work of coaches different from what it is today. The readiness and efficiency in introducing these changes will create differences among competitors in future with dramatic consequences for all stakeholders in that area.

*High-level inferences*: As has been pointed out throughout this paper the real challenges for a coach are inferences on more abstract levels than just observations of positions and actions. If the aim is to generate an efficient game strategy, more abstract inferences are to be drawn, e.g. consisting of only weakly defined terms, with a considerable amount of uncertainty, using soft rules or intuition.

Although this sounds pretty demanding, the situation is not desperate at all for coaching and computer science. The problems mentioned constitute areas in computer science with main focuses in research. For example reconstructing intentions from behavioural data is an important topic as well as reasoning in multi-agent systems. Again, the task for researchers in computer science and coaching will be to direct attention to their interesting field of application and to benefit in this way from technological progress.

*New impulses for sports science*: Some of the developments cited above bear the potential of extraordinary innovations in sports science. If it is possible, for example, to assess the threat a certain positional constellation poses to the opponent's goal in real time, this may be done before and after an action of a certain player, providing a figure for the quality of this action. Adding up these figures we arrive at an objective, quantitative method of assessing the individual performance of a player in team sports, a problem that has seen no viable solution so far. With the same tool of situation assessment it is possible to compare the values of possible alternative actions with the actually chosen one, measuring the efficiency of tactical decisions of players in team sports.

For the area of exercise physiology the future capability of monitoring positions, actions and situations in real time during a game will allow inferences on the state of fatigue of every player at every moment of the game. This should become possible by establishing the individual reactions of players to physical strains which may be found out with some extra investigations under field conditions. Applying these findings for the individual players to their movement profile at a certain point in a match should result in a good estimate of his momentary state of fatigue. Of course, this option is not only of interest for exercise physiologists, but also for coaches. The fatigue level of my own players is an important information for tactical interventions during a match, but estimates for the fatigue levels of the opponent players may be even more valuable for coaching purposes.

*New theoretical approaches*: Finally, with the new quality of future data theoretical progress may be expected. From a dynamic systems perspective monitoring the stream of positions, actions and situations allows for the development of completely new models to describe and understand complex sports. For example, one may become able to describe transient and attractive states of a game, perhaps the idea of a field theory of sports may be realized with the help of these data. There is hardly a limit to perceive what is the potential of computer science and coaching in the near future. It will be decisive, though, whether one will arrive at interdisciplinary projects bringing together the practical questions and demands of coaching with the innovative power of computer scientists.

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