MATHSPORT INTERNATIONAL 2025

3 PARALLEL SESSIONS, 5 KEYNOTE SPEAKERS
AND A MEET&GREET WITH WORLD FAMOUS ATHLETES

BOOK OF ABSTRACTS

JUNE 4TH–6TH | L U X E M B O U R G

COQUE

LUXEMBOURG INSTITUTE OF HEALTH

liroms
LUXEMBOURG INSTITUTE OF RESEARCH IN ORTHOPEDICS, SPORTS MEDICINE AND SCIENCE

Modeling Interdisciplinary Data Science Applied Statistics

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Department of Mathematics

[LU:NEX]

Comité Olympique et Sportif Luxembourgeois

Contents

About

MathSport International Conference 2025

MathSport International organizes biennal conferences dedicated to all topics where mathematics and sport meet. The 2025 meeting takes place in Luxembourg. It is hosted by University of Luxembourg and LUNEX University. It is the 11th conference in Europe that brings together Maths and Sport.

To learn more about the conference, venue and program, check the MathSport International Conference 2025 website (or scan the QR code below).

Organizing committee

Christophe Ley	Florian Felice
Katarzyna Szczerba	Senthil Murugan Nagarajan
Romain Seil	Bernd Grimm
Thorben Hülsdünker	Laurent Carnol
Raymond Conzemius	Alwin de Prins

Timetable

KL: Keynote Lecture, CS: Contributed Session, *: Limited capacity (registration required)

Wednesday, June 4 – Coque

8:00–8:30	**Registration**			
8:30–9:00	**Opening remarks**			
9:00–9:50	KL	**Romain Seil** Amphitheater "*Data Mining Meets Sports Medicine: How Research Impacts Patient and Athlete Care*"		
9:50–10:20	**Coffee break**			
10:20–12:00	CS	**Sports Analytics 1 – S-TRAINING** Amphitheater	**Sports Scheduling 1** Arcades room	**LIHPS Workshop 1*** 11:00-12:00 HPTRC - Speedcourt area
12:00–13:10	**Lunch**			
13:10–14:00	KL	**Paola Zuccolotto** Amphitheater "*Basketball Data Science*"		
14:00–15:40	CS	**Sports Analytics 2** Amphitheater	**Sports Scheduling 2** Arcades room	**LIHPS Workshop 2*** 14:00-15:00 HPTRC - Sprint track
15:40–16:10	**Coffee break**			
16:10–18:10	CS	**Sports Analytics 3** Amphitheater	**Sports Scheduling 3** Arcades room	**LIHPS Workshop 3*** 16:10-17:10 HPTRC - High Performance Lab
19:30–22:00	**Conference dinner** – Coque reception area			

Thursday, June 5 – LUNEX

8:00–9:00	**Commute from Coque to LUNEX**				
9:00–9:50	KL	**Frits Spieksma** Hall O small room "*Scheduling in sports: a Tour d'Horizon*"			
14:50–15:10	**Coffee break**				
10:20–12:00	CS	**Sports Medicine 1** Hall O small room	**Sports Analytics 4** 0.02/0.03	**Sports Analytics 5** 1.01	**LUNEX Workshop 1*** 11:00-12:00 Student lab
12:00–13:10	**Lunch**				
13:10–14:30	CS	**Sports Medicine 2** Hall O small room	**Sports Economics** 0.02/0.03	**Sports Analytics 6** 1.01	**LUNEX Workshop 2*** 13:50-14:50 Student lab
14:30–14:50	**Coffee break**				
14:50–16:30	CS	**Sports Medicine 3** Hall O small room	**Sports Analytics 7** 0.02/0.03	**Sports Analytics 8** 1.01	
16:30–16:50	**Break**				
16:50–17:40	CS	**Sports Analytics 9** Hall O small room	**Sports Scheduling 4** 0.02/0.03	**E-Sports** 1.01	
18:00–19:00	**Commute from LUNEX to Coque**				
20:00–00:00	**Meet & Greet and social dinner**				

Friday, June 6 – Coque

9:30–10:20	KL	**Tim Pawlowski** Amphitheater "*Exploring behavioral responses to reference point-dependent emotions in sports*"	
10:20–10:40		**Break**	
10:40–12:20	CS	**Sports Analytics 10** Amphitheater	**Sports Analytics 12** Arcades room
12:20–13:20		**Lunch**	
13:20–15:40	CS	**Sports Analytics 12** Amphitheater	**Sports Analytics 13** Arcades rooml
15:40–16:00		**Closing remarks – Amphitheater**	
16:00–18:00		**Initiation to indiaca – Coque sports hall**	

Meet & Greet

Andy Schleck

Andy Schleck is a former Luxembourgish professional cyclist. Born in 1985, Andy started his professional career in 2005 and won the individual time trial at the National Championships while his brother Fränk won the road race.

In 2007, he won the young rider classification in the Giro d'Italia and was second in the general classification behind Danilo Di Luca. From 2008 to 2010, he was the best young rider on the Tour de France.

In 2010, Andy takes the yellow jersey of the Tour de France for the first time at the 9th stage. He wears it for 12 days. He was declared winner of the general classification and won the Tour de France 2010 while he also won the white jersey of best young person for the third time.

- 2005 – 🥇 1st at the Luxembourgish National Time Trial Championships
- 2007 – 🥈 2nd overall at the Giro d'Italia and 👕 First young rider
- 2008 – 👕 First young rider at the Tour de France
- 2010 – 🥇 1st at the Luxembourgish National Road Race Championships
- 2009 – 🥇 1st at Liège-Bastogne-Liège
- 2009 – 🥈 2nd overall at the Tour de France and 👕 First young rider
- 2010 – 🥇 1st at the Luxembourgish National Time Trial Championships
- 2010 – 🥇 1st overall at the Tour de France and 👕 First young rider
- 2011 – 🥈 2nd overall at the Tour de France

Jonathan Laugel

Jonathan Laugel is a former french sevens rugby player. Jonathan started his international career with the French under-20 rugby XV team, participating in the 2012 Junior World Championship in South Africa. He transitioned to rugby sevens, making his debut in the 2012 Wellington Sevens tournament and went on to compete in the 2016 Olympics.

Jonathan's main achievements include winning the European Championship in 2014 and 2015. He also participated to the Rio Olympic Games in 2016.

Jonathan retired in 2024, after the Paris Olympic Games where he was not selected to participate as a player but he player a crucial role is supporting the team analyzing matches and bringing his personal experience and view. France won their first rugby sevens gold medal against Fidji Islands.

As a fun fact, Jonathan is known for being the most capped rugby sevens player in France and among the top three worldwide (with 584 appearances).

Jonathan's career include:

- 2012 - 🥈 Silver medal at the South Africa Sevens tournament
- 2014 - 🥇 Gold medal at the Rugby Europe Sevens
- 2015 - 🥉 Bronze medal at the Dubai Sevens tournament
- 2015 - 🥇 Gold medal in mixed doubles at the Rugby Europe Sevens
- 2016 - 🥉 Bronze medal at the Paris Sevens tournament

Anne Simon

Anne Simon is a Luxembourgish basketball player. Born in 2000, in Sandweiler, Luxembourg, she stands at 1.75 meters and plays as a guard. She is known for her scoring ability, defensive prowess, and leadership on the court.

Anne began her collegiate basketball journey at the University of Maine in 2019, joining the Maine Black Bears. Over five seasons, she became one of the most accomplished players in the America East Conference. In her freshman year, she averaged 13 points, 5 rebounds, and 2 assists per game, earning the title of Rookie of the Year. She continued to excel, with her junior year seeing averages of 16 points, 5 rebounds, and nearly 3 steals per game, leading to both Player of the Year and Defensive Player of the Year honors. In her final season, Anne led the conference with 18.9 points per game and contributed 7.2 rebounds and 3.2 assists per game. Her performance helped the Black Bears secure the America East Conference title and a spot in the NCAA Tournament, commonly known as “March Madness”.

After completing her college career, Anne transitioned to professional basketball in Italy, joining Fila San Martino di Lupari in the Serie A1 league. She made an immediate impact, earning the MVP award for December 2024 after averaging 18 points per game and leading her team to a winning streak. In her debut match, she scored 14 points, 4 rebounds, and 1 assist, showcasing her readiness for the professional level. Despite a challenging start to the season with six consecutive losses, Anne’s performance has been a bright spot for San Martino.

Simon’s talents have also shone on the international stage with the Luxembourg women’s national basketball team. At the FIBA Women’s European Championship for Small Countries in 2021, she was named MVP of the tournament, averaging 13.5 points, 4 rebounds, 1.8 assists, and 1.8 steals per game. Her leadership and performance were instrumental in Luxembourg securing the gold medal.

- 2020 - 🥈 2nd overall at the 2019-2020 America East Conference league with Main Black Bears
- 2021 - 🥇 Gold medal at the 2021 FIBA Women’s European Championship for small countries with Luxembourg
- 2024 - 🥇 1st overall at the 2023-2024 America East Conference league with Main Black Bears

Laurent Carnol

Laurent Carnol is a former Luxembourgish swimmer and current Deputy Technical Director at the Luxembourg Olympic and Sports Committee (COSL). Born in 1989, in Ettelbruck, he represented Luxembourg in breaststroke at the Beijing 2008, London 2012, and Rio 2016 Olympics. Notably, he became the first Luxembourger to reach an Olympic swimming semifinal in 2012.

After retiring from competitive swimming, Laurent transitioned into sports administration. In 2021, he was appointed Deputy Technical Director at COSL, where he plays a pivotal role in shaping Luxembourg's Olympic strategies. He co-authored the "Concept Intégré 2.0," a comprehensive 180-page plan aiming to enhance sports integration, performance, and inclusivity across the country. This initiative was presented in May 2025 with the Grand Duke Henri in attendance.

Laurent is also actively involved in supporting dual careers for athletes. He collaborates with LUNEX University to offer scholarships for Luxembourgish athletes pursuing higher education, emphasizing the importance of balancing sports and academics.

In May 2025, Laurent served as Chef de Mission for Luxembourg's delegation at the Games of the Small States of Europe in Andorra, overseeing 164 athletes across various sports.

List of Abstracts

Keynotes

Data Mining Meets Sports Medicine: How Research Impacts Patient and Athlete Care

*by **Romain Seil***

KL

In today's world of sports and health, we collect more data than ever—from motion sensors, GPS trackers, strength tests, and medical records reaching from individual diagnostic and intraoperative imaging tools to large scale registries. But how can we turn all that information into better care for athletes and patients? And which are the barriers to overcome for data acquisition in sports medicine? In this talk, we'll explore data mining—the process of finding patterns and meaning in large datasets — from the clinical perspective and illustrate how it can support injury prevention, better diagnosis, personalized treatment, and safer return-to-play decisions. Using practical examples, we'll show how research helps us understand how the knee is loaded during movement and injury, how data collection can help understand injuries, and how combining test results can guide recovery after surgery. Whether you're a researcher, a clinician, or just curious about how data is changing medicine, this session offers a clear view of how numbers, science, and care can come together to keep athletes healthier and performing at their best. text

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Basketball Data Science

*by **Paola Zuccolotto***

The application of Data Science tools to sports data has been gaining significant popularity recently, capturing the attention of sports managers, coaches, athletes, fans, and enthusiasts. Scientific research in this area is expanding, with innovative methods being developed and new application areas being investigated. Findings are increasingly shared through a growing number of books and scientific articles, published in both specialized journals and dedicated issues focused on specific topics. In 2016, the Big and Open Data Innovation Laboratory at the University of Brescia, Italy (BODaI-Lab, bodai.unibs.it), launched the international scientific network Big Data Analytics in Sports (BDsports, bdsports.unibs.it), coordinated by Paola Zuccolotto and Marica Manisera. The primary goal of BDsports is to establish a broad network of individuals interested in sports analytics, fostering connections between scientists and sports professionals. The project is built on four main pillars: scientific research, practical applications, dissemination, and education, with the latter two focusing on spreading interest in these topics among students and the public. In late 2018, the International Statistical Institute (ISI) entrusted BDsports with creating a new Special Interest Group (SIG) on Sports Statistics. This initiative aimed to further expand the use of Data Science in sports, operating under the official umbrella of ISI, the leading global organization in the field of Statistics. Researchers within BDsports are committed to the analysis of several different sports; however, in this talk, we will focus specifically on basketball. We will summarize the main activities carried out by BDsports across its four pillars, with particular emphasis on scientific research and education. For scientific research, we will outline the main topics explored by BDsports, including the analysis of performance in high-pressure game situations, the identification of new player roles, and the estimation of scoring probabilities from different areas of the court. Regarding the education pillar, we will briefly introduce our book Basketball Data Science and its upcoming second volume, which focuses on advanced topics.

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Scheduling in Sports: a Tour d'Horizon

*by **Frits Spieksma***

At first sight the schedule of any particular league or competition may look like a mundane matter. Indeed, it is obvious that one has to pick certain dates and times for a set of matches to be played. However, that is **not** all there is to it. There is a, sometimes subtle, relation between the schedule and the outcome of the tournament. When one accepts this, it is clear that the schedule should be made with care, ensuring that, among the interests of all other stakeholders, fairness among players or teams, receives the attention it deserves.

We will review examples that shed light on the relation between the schedule on the one hand, and the outcome on the other hand. From these examples, we extract analytical insights that allow us to construct fairer schedules. We illustrate our findings by considering, among others, the Champions League in football, the TATA Steel Chess tournament, and the Premier League of Darts.

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Exploring behavioral responses to reference point-dependent emotions in sports

*by **Tim Pawlowski***

KL

Even though it is a popular claim that emotions play an important role in human behavior [1], robust empirical evidence from the field is scarce. In this keynote I will present a series of studies, where we consider sporting events as an "emotions lab" to explore how emotions influence the behavior of fans during games. More specifically, we closely follow the work by Ely, Frankel, and Kamenica [2] to operationalize reference point-dependent emotions (Surprise and Suspense) and explore their effects on TV viewing behavior [3], Twitter activity [4], and alcohol use [5]. The modelling process in these studies requires the use of different data mining, simulation and machine learning techniques. For instance, to avoid endogeneity concerns when constructing Surprise and Suspense, Study 1 and Study 2 rely on in-play outcome probabilities from simulations. In contrast, Study 3 uses actual in-play odds from an Asian bookmaker minimizing any endogeneity concerns. However, these odds exhibit missing values requiring imputations using Neural Networks. To detect fans, haters, and neutrals from sentiment released in Tweets, Study 2 relies on Natural Language Processing tools. Finally, because of the complex hierarchical nature of our model in Study 3, we implement a recursive algorithm based on Hamiltonian mechanics.

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Sports Analytics 1

Basketball Data Science: Statistical Methods for Shooting Performance Mapping

by ***Marica Manisera***, Paola Zuccolotto **CS** SA011

The increasing availability of sports data and advanced analytical tools has enabled the exploration of critical questions in basketball through data science. While temporal analysis represents one avenue for performance evaluation, this contribution focuses on statistical methodologies for constructing shooting performance maps. Using play-by-play data, we analyze shot performance through spatial patterns, leveraging advanced statistical techniques such as classification and regression trees (CART), random forests, and indicator kriging. CART models partition the court into subareas, optimizing distinctions in scoring probabilities and identifying homogeneous zones for shot outcomes. Polar coordinate systems are employed to refine spatial analysis, capturing efficiency patterns in relation to angles and distances. Random forests extend these insights by offering probabilistic estimates, while indicator kriging applies geostatistical models to interpolate scoring probabilities across the court. These methods provide innovative tools for visualizing and understanding shooting dynamics, enabling players, coaches, and analysts to develop data-driven strategies. By focusing on spatial analysis, this contribution advances the field of basketball data science, offering practical solutions for performance evaluation and tactical decision-making. Real-world examples based on recent data will be presented to illustrate the proposed methodologies and their applications.

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Using shooting trajectories for basketball predictions

by ***Ambra Macis***, Marica Manisera, Marco Sandri, Paola Zuccolotto **CS** SA012

Predicting outcomes is one of the most attractive topics in basketball analytics. Three-point shots play a crucial role in winning a game; therefore, there is significant interest in predicting their outcome and identifying the key variables that increase shot success. This contribution aims to use shooting trajectories to predict whether a three-point shot will be successful or not in the National Basketball Association (NBA) League. The analysed data refer to the 2015-2016 NBA regular season, and come from a publicly available NBA SportVu dataset. First, a thorough data cleaning process was necessary due to the presence of irregular ball trajectories. This process involved multiple steps, including model-based recursive partitioning and the evaluation of a straightness index to identify and exclude anomalous trajectories. Next, a parabolic model was fitted to each trajectory, and its parameters were recorded in a dataset along with additional relevant information, such as shot angle and speed. Finally, a range of statistical methods was employed to predict the outcome of three-point shots.

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Data-Driven Lineup Optimization in Wheelchair Basketball

by ***Gabriel Calvo***, Carmen Armero, Bernd Grimm, Christophe Ley **CS** SA013

Wheelchair basketball is played in 104 countries, and according to the International Wheelchair Basketball Federation (IWBF), there are more than 100.000 players worldwide. A distinctive feature of wheelchair basketball is the Player Classification Points System (PCPS), implemented in all team sports for athletes with physical disabilities. This system assigns each player a classification on a scale from 1 to 4.5, reflecting the range from minimal to maximal physical capacity. The sport's key regulation mandates that, during gameplay, the combined classification points of all players on the court must not exceed a 14-point limit. Developing tools to aid lineup selection is valuable in any team sport but becomes particularly critical in contexts where a PCPS and maximum-point constraints are in place. In this presentation, we introduce a data-driven tool designed to generate optimal lineups by leveraging basketball performance metrics (e.g., points, rebounds, assists, steals, blocks, fouls drawn, missed field goals, missed free throws, turnovers, etc.) for a specified pool of eligible wheelchair basketball players. The proposed methodology follows a three-step approach:

- Performance analysis: Player performance data are analysed using a Bayesian longitudinal model to identify trends over time.
- Performance prediction: Future player performance is forecasted for upcoming matches based on the posterior predictive distribution of the Bayesian model.
- Lineup optimization: Using the predicted performance metrics, optimal team compositions are determined by solving a linear optimization problem that incorporates variability from the posterior predictive distribution.

This methodology was applied to the Doneck Dolphins Trier, a team competing in the German Rollstuhlbasketball-Bundesliga (RBB). The results demonstrate the effectiveness of our approach in identifying the most efficient team compositions while respecting the PCPS constraints. This study offers a novel perspective on team optimization in wheelchair basketball by integrating advanced performance analysis with the regulatory framework of the sport.

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AI for Handball: predicting and explaining the 2024 Olympic Games tournament with Deep Learning and Large Language Models

by ***Florian Felice***

CS SA014

Over summer 2024, the world will be looking at Paris to encourage their favorite athletes win the Olympic gold medal. In handball, few nations will fight hard to win the precious metal with speculations predicting the victory for France or Denmark for men and France or Norway for women. However, there is so far no scientific method proposed to predict the final results of the competition. In this work, we leverage a deep learning model to predict the results of the handball tournament of the 2024 Olympic Games. This model, coupled with explainable AI (xAI) techniques, allows us to extract insightful information about the main factors influencing the outcome of each match. Notably, xAI helps sports experts understand how factors like match information or individual athlete performance contribute to the predictions. Furthermore, we integrate Large Language Models (LLMs) to generate human-friendly explanations that highlight the most important factors impacting the match results. By providing human-centric explanations, our approach offers a deeper understanding of the AI predictions, making them more actionable for coaches and analysts.

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Forecasting In-Game Win Probabilities in Handball: Evaluating the Impact of Goalkeeper Substitution

by ***Rouven Michels***, Dimitris Karlis **CS** SA015

Handball is a dynamic sport where in-game decisions play a critical role for the outcomes of matches. As one example, coaches are often faced with the question of when it is strategically advantageous to pull the goalkeeper and replace them with an additional field player to maximize their team's chances of winning. This study aims to address this decision-making challenge by developing a comprehensive modelling framework to forecast in-game win probabilities based on the current state of play and provide real-time tactical recommendations for handball coaches. To achieve this, we use live ticker data from six full seasons of the German Handball Bundesliga, one of the most competitive handball leagues in the world. The dataset includes contextual information such as the remaining time in the game, score difference, team penalties, and pre-game betting odds - factors that influence both tactical decisions and game dynamics. These variables serve as inputs for our models to provide real-time predictions about win probabilities under different scenarios. We evaluate a range of statistical and machine learning approaches for predicting instantaneous win probabilities. In particular, we employ multinomial logistic regression models as well as machine learning approaches like Random Forests and XGBoost to predict instantaneous win probabilities during the game by estimating the likelihood of each potential match outcome (win/draw/loss). These models are chosen for their ability to handle variable selection and complex interactions between variables and provide probabilistic forecasts for any given scenario. However, these methods face challenges related to observational dependency since multiple events within a single game are inherently correlated because they share common outcomes. This dependency can result in biased estimates if not properly accounted for within the model structure. To address these temporal dependencies more explicitly and capture the sequential nature of handball games, we also explore attack-by-attack simulation approaches that model transitions between different game states over time. These simulations allow us to dynamically evaluate how decisions such as substituting the goalkeeper affect future scoring opportunities and defensive risks under varying conditions. For each approach, we identify specific situations where substituting the goalkeeper for an additional field player increases or decreases the winning chances. Moreover, we compare these methodologies in terms of predictive accuracy, uncertainty quantification but also computational speed as the models should serve as data-driven recommendation tool to optimize coaches' strategies in real-time during matches. In doing so, this research not only enhances our understanding of how key tactical decisions impact match outcomes but also introduces a novel data-driven framework specifically tailored for handball - a sport where advanced analytics have been underexplored compared to other professional sports like football or basketball.

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Sports Scheduling 1

Round-Robin Tournament Scheduling Under Total Game Attractiveness Objective

by ***Tankut Atan***, Uğur Güler, Tankut Atan, Dilek Günneç **CS** SSO11

Tournament competitiveness plays a critical role in shaping the associated economy, influencing match attendance, viewership, merchandise sales, and related factors. Among various measures that can help increase tournament competitiveness, scheduling offers a cost-effective way for this purpose. Designing a tournament schedule with competitiveness in mind can significantly enhance a tournament's appeal. In this study, we present a new metric, the competitive difference, to measure this appeal and propose a mathematical model tailored for round-robin tournaments. While our numerical experiments involve single round-robin tournaments, the approach can be extended to multiple round-robin tournaments as well. Using simulated match outcomes, we evaluate the impact of the generated schedules on the Big Five leagues.

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Break minimization in incomplete round-robin schedules

by ***Sebastián Urrutia***, Dominique de Werra **CS** SS012

In round-robin schedules, a break occurs when a team plays two consecutive home or away matches. Minimizing breaks is important for ensuring competitive fairness and logistical efficiency. This research addresses the problem of minimizing breaks in incomplete round-robin schedules, a classic problem that was previously thoroughly studied in the context of complete round-robin schedules. Using graph-theoretic tools, we model the scheduling problem as a graph optimization task, enabling the analysis of structural properties and the derivation of theoretical bounds. Specifically, we determine the maximum number of rounds possible in an incomplete round-robin schedule while restricting the number of breaks to zero. Additionally, we establish bounds for the minimum number of breaks for varying numbers of teams and rounds, providing a comprehensive framework for understanding the trade-offs between schedule length and break minimization.

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Increasing competitiveness by imbalanced groups in the FIFA World Cup

by ***András Gyimesi***, László Csató **CS** SSO13

The design of the 2026 FIFA World Cup has gone through a significant reform with the expansion to 48 teams. In 2023, FIFA has decided for a new structure featuring 12 groups of four teams each, which is followed by a knockout stage starting from the Round of 32. The revised format aims to reduce the risk of collusion and guarantees at least three matches for each team. However, a significant concern remains regarding the occurrence of non-competitive or "stakeless" matches, where a team has few incentives to exert full effort because they already have secured qualification or have been eliminated. This talk critically evaluates FIFA's new format and proposes an alternative design based on imbalanced groups. The key idea is to divide the 48 teams into two tiers: eight groups of stronger teams (Tier 1) and four groups of weaker teams (Tier 2). While Tier 1 group winners directly qualify for the Round of 16, Tier 2 group winners and runners-up compete in a play-off round against Tier 1 runners-up. This format is inspired by examples from handball and water polo. To compare the two designs, Monte Carlo simulations based on Elo ratings are used. We focus on the probability of stakeless matches for different teams. In particular, a stakeless match is assumed to be more costly if the team with the lack of incentives a) has already qualified to the next round, and b) has a priori a higher chance to win the match. The results reveal that the imbalanced group format offers several advantages over the official design. First, it substantially reduces the proportion of stakeless matches, especially in the more costly cases. Second, it contains fewer matches, especially for the strongest teams whose players have the highest workload during the season. Third, it increases the number of high-quality matchups by ensuring that the top teams face stronger opponents in average. While the current format of the 2026 FIFA World Cup undeniably represents an improvement over earlier proposals, our findings suggest that further refinements are possible. The proposed imbalanced group format offers a viable alternative that maintains fairness while maximises excitement and competitiveness. These insights contribute to the broader literature on tournament design and can inform future discussions on optimising large-scale sporting events.

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The Split: Analysing Contest Design in the Scottish Premier League

by ***Jessica Hargreaves***, Johan Rewilak **CS** SS014

In this talk, we examine whether changes to league structure (to "split" the league in two after 33 games for post-season play) in the Scottish Premier League (SPL), generated any negative externalities. Specifically, by using a regression discontinuity (RD) design we test if this policy facilitated "tanking" by reducing the incentive to apply costly effort in a sporting contest and whether it reduced attendances for teams finishing in the lower half of the standings. The data used are drawn from 23 completed seasons (from 2000/01 to 2023/24, excluding pandemic-impacted seasons) in which the institutional arrangement has been in place in Scotland's elite tier of professional soccer. There is weak support of mid-table teams tanking, but teams above/below the cut-off perform (tank) similarly Post-Split. This result shows that the tanking phenomenon is not just apparent in closed leagues. However, teams just below The Split have inferior attendances relative to those just above and this is driven by the lost opportunity to play against the "top" teams, such as Celtic and Rangers. This implies that the new structure was harmful to a subset of clubs. Furthermore, this work highlights the reliance on big teams in sports leagues and their role in subsidizing smaller market teams. Finally, we introduce an open source web application in R-Shiny that we developed to generate interactive visualisations of attendance data in the SPL.

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The myth of declining competitive balance in the UEFA Champions League group stage

by ***Dóra Gréta Petróczy***, László Csató **CS** SSO15

One of the most prestigious football tournaments, the UEFA Champions League, has been organised in the same format over 21 seasons between 2003/04 and 2023/24, which is fundamentally changed from 2024/25. The reform explicitly aims to improve competitive balance by replacing the traditional group stage with an incomplete round—robin league phase. According to previous studies, competitive balance has significantly declined in the UEFA Champions League group stage over the recent decades. Our paper aims to check the robustness of these findings by considering alternative measures of competitive balance. We introduce six indices for measuring ex ante and ex post competitive balance. The ex ante measures are based on Elo ratings, while the ex post measures compare the group ranking to reasonable benchmarks. No evidence is found of any trend in the competitive balance of the UEFA Champions League group stage between the 2003/04 and 2023/24 seasons. Consequently, if UEFA has chosen the barely used incomplete round-robin design of the Champions League with its inherent risks because of the worsening trend in competitive balance, the decision-makers might have been misled.

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Sports Analytics 2

Mathematical models for speed climbing applied to data collected on competitors in recent World Cup events

*by **Luca Benga***, Luca Benga, Benjamin Hatch, Dana Sylvan **CS** SA021

Speed climbing is one of the newest Olympic sports, debuting at the 2020 Tokyo Olympics. With many races decided by hundredths of a second, speed climbing quickly gained recognition as the fastest sport at the Paris 2024 Olympics. Speed climbing appeals to data scientists since it uses a standardized 15-meter wall, making it easy to compare times and strategies across a vast array of competitions and competitors. Surprisingly, however, to the best of our knowledge, there has been little rigorous analysis of a professional level race. In this paper, we model data compiled from the 2023 World Cup events in Wujiang, China and Salt Lake City, USA, analyzing both numerical and categorical variables. Examples of quantitative variables include the reaction time displayed in the video for each athlete, along with the total time, or split times, obtained by running the recording for each athlete frame by frame and estimating the exact point at which each section is reached. An example of a binary variable is the skips strategy, which draws attention to the holds each athlete omits on their run. Another example of a categorical variable is the round designation - either round 1 or round 2 - which refers to the order of athletes' runs.

We explored these variables extensively, built several general linear models for athlete performance and used model selection to determine the best predictive models. We found that reaction times are normally distributed and appear to be very weakly correlated from one race to another. Counterintuitively, however, they appear to have minimal bearing on the race result, despite making up a portion of the overall time. Another interesting observation is that many athletes attempt a more aggressive skip strategy in their second run, omitting a greater number of holds. This is either because they either already recorded a viable time for qualification in Round 1 and can afford the risk, or because they felt the need for substantial improvement.

In ongoing work, we have been focusing on expanding the analysis, using data from additional World Cup events for both men and women.

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A dynamic extension of the Massey's rating system based on a multivariate score-driven time series model

by ***Paolo Vidoni***, Enrico Bozzo **CS** SA022

This paper proposes a flexible, dynamic extension of the popular Massey's method for rating players and teams involved in sports competitions. Massey's original approach is static as the calculation of a team's rating is based on the strength of the opponent teams evaluated at the current evaluation time. The proposed dynamic extension updates the rating of each team considering the strength of the opposing teams evaluated at the time the matches were played. This approach adequately takes into account the fact that teams' capabilities change over time. More precisely, the method accounts for the evolution of both the offensive and the defensive rating for each team and it also describes the temporal change of a team-specific home field advantage parameter. The associated dynamic multivariate statistical model belongs to the wide class of score-driven time series model (see, e.g., Creal, D.D., Koopman, S.J., Lucas, A., 2013. Generalized autoregressive score models with applications. Journal of Applied Econometrics, 28, 777-795). The time-varying parameters, namely the offensive and the defensive strengths and the home field advantage, are evaluated sequentially using a suitable score-driven updating algorithm. Thinking of basketball applications, we initially assume that the data, that is the results of matches, are generated by a multivariate Gaussian distribution and then we also consider a multivariate t distribution, which has proved useful in describing cases where high match scores are observed. This model is flexible and easily extensible by introducing, for example, suitable team- and game-specific covariates. The goodness of fit of the model and its predictive ability were evaluated and also compared with those of other dynamic extensions of Massey's method. In particular, an application of the new rating procedure in basketball is proposed, focusing on the results of some recent NBA seasons.

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Teaching probability theory through tennis

*by **Tristan Barnett***, Anthony Bedford, Erica Mealy **CS** SA023

This article obtains distributional characteristics for the length of a tennis game. Although the mean and variance help to describe the distribution, it is demonstrated that these two characteristics are insufficient for measuring 'risk' and therefore other characteristics such as the coefficients of skewness and excess kurtosis are obtained. By setting up recursion formulas with the appropriate boundary conditions in spreadsheets the first four moments of the total number of points played in a game conditional on the point score are obtained, which in turn are converted to distributional characteristics. This could form an interesting teaching exercise in using Excel and probability theory.

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Revisiting Clutch Performance Among Elite Players in Tennis

by ***Pascal Bauer***, Jan Bauer **CS** SA025

The question of whether elite tennis players perform significantly better at decisive points was first raised in 2004 by Pollard & Graham. Following Morris' (1977) definition of important points, they demonstrated that one player (Andre Agassi) performed above his average point conversion rate for these points over seven matches during the 2003 Australian Open. More recently, Díaz et al. (2012) provided evidence that top players perform better "when it matters most" (1,009 matches), while Kovalchik & Reid (2018) introduced a metric to quantify clutch performance. They showed that an importance-weighted point rate predicts match outcomes more accurately than naive point aggregations (305 men's / 296 women's Grand Slam matches). However, none of these studies conclusively determined whether clutch performance among top players truly exists. To further investigate this question, we analyze a dataset of 93,884 professional men's matches from January 1991 to May 2024. First, we implement a linear regression model to predict players' career match-winning rates based on their average serve and return rates, achieving an R^2 of .94. Second, we simulate tennis matches on a point-by-point basis using fixed serve and return point-winning rates to explore the S-shaped correlation between point- and match-winning rates. Feeding these simulations with real-world data reveals that these correlations closely align with players' actual career statistics (RMSE of 2.4% in match-win percentage). Lastly, building on the work of Klaassen & Magnus (2001), we compare the observed frequencies of the world's top 20 players' performances with expected frequencies under a uniform distribution. While we do not find strong evidence that top players' point-winning distributions deviate from a uniform distribution, we identify weak artefacts for some elite players. Specifically, the null hypothesis of a uniform distribution (5% significance level) is rejected for the return performance of Rafael Nadal, Novak Djokovic, Daniil Medvedev, and Carlos Alcaraz. However, exploratory analysis suggests that these deviations may instead result from intended tactical behavior, such as saving energy when returning at 40–0. We apply the same methodologies to women's professional tennis matches (66,000 matches), yielding similar results. Overall, we revisit previous research and common beliefs about clutch performance of elite tennis players using three different methods and a significantly expanded dataset. Future research should further support these findings by incorporating in-game-win-probability models from other sports into tennis.

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Optimizing Goal-Scoring Decision-Making with Machine Learning: A Real-World Use Case for Racing de Santander of the Spanish Second Division Football League

by ***Manuel Duran***, Sebastian Ceria, Andres Farall, Guillermo Duran, Nicolas Marucho, Ivan Monardo, Federico Rabanos, Pablo Mislej, Diego Brunetti

CS SA026

Nowadays, Expected Goals (xG) models are an essential part of football analytics, yet there is significant room for improvement in capturing the complexity of in-game decision-making. In addition, we extend their application as a decision-support tool to evaluate post-shot goal probability based on different eventing and tracking data. In this work, we present a machine learning and deep learning-based approach designed to optimize shot selection and maximize the probability of scoring. Developed in collaboration with Racing de Santander, currently on La Liga Hypermotion, the Spanish Second Division, our model integrates eventing data and advanced tracking data—such as player trajectories, velocities, positioning, and pass history—refined through expert input from the club's technical staff. Beyond conventional xG calculations, our approach functions as a decision-support tool, allowing for scenario-based evaluations of goal probability across different shot placements. By analyzing various real in-game contexts, we estimate the likelihood of scoring for each target area within the goal, providing actionable insights for players to make optimal shooting decisions. This system is actively employed to enhance finishing training sessions for professional footballers, reducing the gap between data-driven insights and real-world performance optimization. By leveraging visual graphs and probability heatmaps of the goal, we aim to communicate insights more effectively to the club's professionals, making data-driven recommendations more intuitive and actionable for players and coaching staff.

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Sports Scheduling 2

Trade-off between attractiveness and equal treatment in tournament draws: A case study from handball

by ***László Csató***, Dóra Gréta Petróczy **CS** SSO21

National teams from different continents play against each other in a limited number of sports competitions. Therefore, it makes sense to maximise the number of intercontinental games in these tournaments, such as world championships, as done in basketball and football. However, this requires draw constraints that violate the axiom of equal treatment. In addition, the standard draw procedure is non-uniformly distributed on the set of valid assignments, which may imply further distortions. Our paper analyses this trade-off through the example of the 2025 World Men's Handball Championship. All combinations of reasonable geographical restrictions are considered to determine the Pareto frontier between the number of intercontinental games and the level of inequality. The proposed methodology can be used by organisers to choose the optimal set of draw constraints.

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The league phase in UEFA competitions

*by **Dimitris Karlis***

CS SSO22

Since 2024-2025 UEFA decided to change the format of European competitions introducing a league phase aiming at increasing interest. The new format replace the group stage by a league phase. In Champions League, a total of 36 teams competed in the league phase to decide the 24 places in the knockout phase. Each team played eight matches, four at home and four away, against eight different opponents, with all 36 teams ranked in a single league table. Teams were separated into four pots based on their 2024 UEFA club coefficients. Each team played two teams from each of the four pots – one at home and one away. The top eight ranked teams received a bye to the round of 16. The teams ranked from 9th to 24th contest the knockout phase play-offs, with the teams ranked from 9th to 16th seeded for the draw. Teams ranked from 25th to 36th were eliminated from all competitions, with no access to the 2024–25 UEFA Europa League. A critique on the league phase is that teams play with other teams of various abilities and this can introduce some bias. In this talk we investigate the fairness of the league phase to decide the best teams. This is based on a model based approach where a model from the matches given is used to extrapolate for a full round robin tournament. Special care is given to eliminate potential biases due to the small number of games given.

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Integrating score predictions in prescriptive sports scheduling models

by ***Jonas Andersson***, Mario Guajardo, Dimitris Karlis **CS** SSO23

The literature on sports analytics has covered a broad range of tournament scheduling problems. These problems are often addressed by prescriptive models in a deterministic setting. The main aim of these models is to prescribe decisions on when and where should each team play against each other over the course of a season. In parallel, another body of literature in sports analytics has developed probabilistic models to predict the outcome of the games. Despite the large amount of works in these two streams of literature, so far little effort has been made to combine both prescriptive and predictive models into a single framework. The aim of this work is to bridge this gap, by developing sports scheduling models which take into account outcome prediction models. We illustrate how the resulting schedules may be affected in a problem where the performance of a team depends on the outcome of its previous games. Since the scheduling problem must typically be solved before the season starts, when the outcomes of the games are still unknown, the incorporation of information from the predictive approach becomes important. Moreover, assuming that the outcome of the games realize according to a maximum probability criteria, we show that different schedules may have large impact in the final standings of the tournament.

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The impact of imbalanced groups in UEFA Euro 1980–2024 and comparison with the FIFA World Cup

by ***Michael A. Lapré***, Julia G. Amato **CS** SSO24

Prior research found significant competitive imbalance in FIFA World Cup tournaments because FIFA does not allocate World Cup slots to continental confederations in proportion to the distribution of the best teams in the world. Since the UEFA Euro only consists of teams from Europe, it should be much easier for UEFA to create competitive balance. We empirically investigate competitive imbalance between groups at the UEFA Euro tournaments from 1980 through 2024. We find that competitive imbalance at the Euro is just as bad as it is in the World Cup. We also find that the impact of competitive imbalance on the probability of reaching the quarterfinals is the same across the World Cup and the Euro. UEFA creates competitive imbalance by sometimes protecting multiple low-ranked hosts and, most importantly, using inadequate methods to rank teams. We recommend that UEFA adopt an Elo rating system to rank teams.

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The Effect of a Structural Change in Round-Robin Tournaments with Four Teams: Evidence from Beach Volleyball

by ***Alex Krumer***, Alessandro Di Mattia, Alex Krumer **CS** SSO25

This paper explores the impact of a reduction in the number of matches in a widely used round-robin tournament format between four teams. This is done by taking advantage of a structural change in professional beach volleyball in 2017 that reduced the number of matches played by each team in the round-robin (pool) stage from three to two. The format shifted from a traditional round-robin format, in which each of the four teams played against all the other teams for three matches, to a format in which the initial matches were played between the highest-ranked team against the lowest and the second highest against the third. In the subsequent round, winners faced winners and losers faced losers. Using data on 6975 matches, our multivariate regression analyses find that the decrease in the number of matches in a pool does not affect the efficacy of the tournament, as measured by the probability of a favourite team winning a single match and by the natural order of the final standings based on the teams' initial strengths. The results are robust to different definitions of teams' strength and for both genders. We also find a substantial decrease in retired and forfeited matches with the new format. These findings offer a promising alternative to the FIFA World Cup and other round-robin tournaments with four teams.

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Sports Analytics 3

Identifying Soccer Styles

by ***Tim Swartz***, Tianyu Guan, Sumit Sarkar **CS** SA031

This talk concerns a problem in soccer analytics that relies on tracking data. We develop a metric that identifies soccer players who have a similar style to a player of interest. Whereas performance variables have been widely studied, the same is not true of stylistic variables. Unlike assessments from scouting, the metric is automatic and objective. The metric is developed using a Bayesian framework.

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Bayesian modeling of goal arrival times

by ***Ioannis Ntzoufras***, Ilias Leriou **CS** SA032

Prediction and modeling of association football (soccer) outcomes has gained increasing interest in the scientific community in recent years, both due to betting concerns and the need for a deeper understanding of the factors influencing soccer events. We introduce and examine the validity of a Bayesian model, which belongs to the class of accelerated failure time (survival) models and is characterized by its straightforward structure. We implement MCMC methodology to estimate the posterior summaries of the model parameters and suggest a novel algorithm that can be used to transform simulated goal arrival times into predicted goals. The proposed model achieves exceptional in-sample and out-of-sample performance by replicating the entire league in a remarkably precise manner and by making accurate predictions on the second half of the league using the first half as a training dataset. The structure of the proposed model is extendable, allowing for the inclusion of in-play covariates that can be used to further map the complex dynamics of soccer matches.

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Scoring probability maps on the basketball court through Spatial Point Pattern analysis

by ***Mirko Carlesso***, Paola Zuccolotto, Marica Manisera, Andrea Cappozzo, Andrea Gilardi **CS** SA033

Measuring players' and teams' shooting performance on the basketball court is a critical aspect of understanding game dynamics and optimizing both game strategies and personalized training programs. The accurate evaluation of scoring probability provides valuable insights that can directly influence coaching decisions, player development, and overall team efficiency. From a methodological perspective, this problem has traditionally been approached using various statistical and algorithmic modeling tools. Among these, spatial statistics emerges as the most natural theoretical framework, as it allows for the analysis of shooting performance in a way that explicitly accounts for the spatial distribution of shots. In this work, we present a novel approach that leverages the spatial point pattern framework, treating made and missed shots as events of a spatial point pattern on the basketball court. This framework shifts the focus from traditional binary outcome models to an analysis that incorporates the spatial nature and distribution of shot attempts. By modeling the intensity of the process, we provide a robust foundation for understanding how shot attempts are distributed and how scoring probabilities can be derived from these distributions. Furthermore, we propose a methodology for creating scoring probability maps that visualize shooting performance across the basketball court, offering valuable insights to better understand shooting dynamics and inform decision-making in both strategy and training. To validate this approach, a structured case study is presented, dealing with all the teams of the Italian Basketball First League, based on a non-public dataset.

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Training Periodization and Load Coupling in Speed Skating

by ***Matthias Kempe***

CS SA034

High-performance sports require optimal training periodization to maximize adaptation, avoid injury or overtraining, and achieve peak performance. The intensity distribution of training (TID) in endurance sports has been widely studied; however, its application to short-track speed skating remains unexplored. Additionally, understanding the coupling of internal and external training load is critical to designing effective training programs in speed skating. This paper presents two studies. The first investigates whether elite short-track speed skating periodization aligns with commonly proposed TIDs. The second evaluates the utility of bivariate kernel density estimation (KDE) to capture and visualize the coupling of internal and external training load in junior (sub)elite speed skaters.

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So the last will be the first

by ***Ruud Koning***, Manon Grevinga, Antoine Roger **CS** SA035

It is well known that different competition formats in sports result in different conditions for the athletes. For example, it is well known that average effort provided by equally skilled athletes decreases with the number of participants in a winner take all contest. Some tournament types base ranking on some absolute measure of performance, so essentially all athletes compete against each other, even though they may not compete simultaneously. In such a case, incentives are similar to the ones in a single rank order tournament, and so is effort provided. In such tournaments, information and peer effects may be influence performance of the individual athlete.

In this paper we focus on speed skating and address the question to what extend skaters respond to the information available. We find a small and significant effect of the best time skated so far: if the best time skated so far decreases by 1 second, performance of the skater improves by approximately 0.17%-0.42% (depending on the specification). Even though this effect appears to be very small, it may be significant as the time difference between top places of important tournaments may be tiny.

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Statistical Analysis of Action Player Contribution in Soccer

by ***Rodolfo Metulini***, Mattia Cefis, Maurizio Carpita **CS** SA036

Football analytics has increasingly relied on advanced data-driven approaches to assess player performance and team strategies. In this study, we introduce a novel dataset for football analytics that integrates detailed event and performance data from the Italian Serie A 2022/2023 season. The dataset is constructed through an advanced ETL process, combining information retrieved via web-scraping from WhoScored.com, Understat.com, and SoFIFA.com. It comprises over 8,400 shot actions and includes a wide range of contextual variables, such as pass details, player roles, pitch coordinates, and performance indices derived through Partial Least Squares Structural Equation Modelling (PLS-SEM). The dataset enables a more comprehensive analysis of player contributions by incorporating detailed event sequences and passing networks. Building upon this resource, we propose an innovative approach to evaluating the marginal contribution of players in soccer using a cooperative game approach and the expected Goal (xG) model as a cohesion function. Thanks to the information in our dataset, we can dynamically define coalitions as the set of players actively involved in a given action. This novel representation based on passing networks allows for a more granular evaluation of both individual and positional contributions.

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Sports Scheduling 3

Drawing and Scheduling Matchups in the New UEFA Champions League Format

by ***Julien Guyon***, Adle Ben Salem, Thomas Buchholtzer, Mathieu Tanré **CS** SS031

During the league phase of the new UEFA Champions League, 36 teams are ranked in a single table. Each team faces only eight opponents that are randomly drawn, subject to seeding pot and association constraints. We investigate four methods for drawing the league phase matchups. First, we consider the official draw procedure used by UEFA, where matchups are drawn before the match schedule is built. We show, using a graph-theoretical argument, that the scheduling issue cannot be completely ignored when matchups are drawn, by exhibiting a draw outcome which satisfies all the pot and association constraints but is noncompact, i.e., cannot be scheduled within the allocated eight match days. Second, we study an alternative method where one first builds a schedule template before randomly populating it with the 36 teams. We show that the minimum number of breaks is equal to 4 and explicitly build a template that minimizes the number of breaks and optimizes various fairness and TV exposure criteria. For both methods, we consider a randomized variation where the order of pots from which teams and their opponents are drawn, for the first method, and the order with which we populate the schedule template, for the second method, are randomized. We implement the four methods using integer programming to enforce the draw constraints, and run Monte Carlo simulations to compare their fairness, via the distributions of average opponents' strength, in the case of the 2024-25 UEFA Champions League and the 2024-25 UEFA Europa League, which follows the exact same rules. We also compare the matchup probabilities produced by the four procedures, and introduce a luck index that objectively ranks teams from the luckiest to the unluckiest during the actual draw. As an interesting aside, we provide examples of noncompact draw outcomes and derive the minimum number of scheduling breaks for more general setups with p seeding pots, q teams per pot, and where each team faces k opponents from each pot.

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A multi-league traveling tournament problem for FIFA and UEFA's main tournaments: Do they really minimize distances?

by ***Mario Guajardo*** **CS** SSO32

In many sport tournaments, teams are divided into groups to contest during a first stage. This first stage often consists of a single round robin tournament within each group. For example, the FIFA World Cup and the UEFA Euro feature groups of four teams, where each team plays once against each of the three opponents in its group. The games are usually held on a limited number of venues across one or few host countries. Each venue may host games from different groups, typically with some days of separation. The first purpose of this paper is to define and model a general problem for this type of tournament, in which the main decisions are when and where should each game be played. The problem can be classified as a multi-league scheduling problem with multiple shared venues and other practical features. Secondly, this paper addresses such problem in the 2024 UEFA Euro and the 2026 FIFA World Cup cases, with particular focus on the minimization of distances. In fact, when it comes to schedule the games of these tournaments, both UEFA and FIFA organizers have publicly stated to care about the distances travelled by teams and fans. By running different variants of an optimization model which minimizes a distance function subject to different criteria, this talk will show schedules that outperform the actual schedules released by FIFA and UEFA.

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Implications of the UEFA Champions League's New Swiss-Style Format: A Simulation Study

*by **Stephen Hill*** **CS** SSO33

The 2024-25 UEFA Champions League introduced a significant format change, replacing the traditional group stage of the competition with a 36-team league phase using a Swiss-style tournament structure. While commonly referred to as a "Swiss system," the new format incorporates modifications such as a pre-determined list of fixtures for each club and the use of a pot-based system for fixture draws. This study employs Monte Carlo simulation methods to compare this new format with a traditional Swiss system, the previous group stage structure, and other tournament formats. We examine the relative impacts of tournament format on competitive balance and expected outcomes.

Our analysis addresses two key dimensions. First, we examine how UEFA's modified Swiss-style format affects competitive balance. We develop probability distributions for knockout phase qualification and analyze how these distributions are affected by tournament format and other factors. Second, we investigate how matchmaking constraints—including country protection rules and coefficient-based seeding—influence schedule equity and tournament outcomes

Our findings seek to quantify the tradeoffs between different tournament formats and highlight how effectively UEFA's hybrid approach balances competitive considerations. These results have important implications for tournament design in professional sports, offering insights into how structural modifications to established formats affect competitive balance.

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Optimizing professional sports league games based on spectators and traveling

*by **Jari Kyngäs***, Kimmo Nurmi, Arto Järvelä **CS** SS034

Professional sports leagues are huge businesses. The quality of the schedules has become increasingly important, as the schedule has a direct impact on revenue for all involved parties. Most importantly, the schedule influences the number of spectators in the stadiums and the traveling costs for the teams. Most of the professional leagues play a round robin tournament, where each team plays against each other a fixed number of times.

The Finnish Major Hockey League decided to promote one team to the league for the season 2024-2025. This means that there would be 16 teams in the league, and this causes problems to the formerly used base schedule. The number of games cannot exceed 60, but the most attractive games must be preserved. The base schedule is based on a four round robin tournament which would end up with exactly 60 games and leave no room for extra number of the most attractive games.

Therefore, a new approach had to be considered where every team should meet every other team at least once, for the sake of sportsmanship. The rest of the games would be decided based on the number of spectators and traveling.

This paper presents an unbalanced format, where the number of times the teams play against each other is based on maximizing the total expected number of spectators and on minimizing the total traveling. The effect of an unbalanced format to the quality of the final schedule is shown by using a real-world example from the Finnish Major Ice Hockey League. The results show a 5% increase in the number of expected spectators, and a 10% decrease in traveling. To the best of our knowledge, this is the first time such an optimization problem has been introduced.

This kind of schedule would probably be opposed by the “small” teams because they get to meet the big clubs less frequently. If this kind of schedule would someday be used the smaller clubs should probably receive some kind of compensation for this.

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Optimization of the Tournament Format for the Nationwide High School Kyudo Competition in Japan

by ***Eiji Konaka***, Kazu Nishikawa and Eiji Konaka **CS** SSO35

This study investigates the optimization of the tournament format used in the nationwide high school Kyudo tournament in Japan. Kyudo, or Japanese archery, is a traditional sport in which participants aim to hit a target using a bow and arrow. Unlike other target sports, such as Olympic archery or shooting, Kyudo employs a binary scoring system: only whether an arrow hits the target is considered, without accounting for the distance from the center. While preserving the traditions of the sport, this scoring method presents a challenge in accurately evaluating the skill levels of participants, particularly when the number of attempts is limited. The nationwide high school Kyudo tournament includes competitors who have won regional qualifications. It is both a competitive event and an opportunity to provide students with educational and training experiences. Therefore, the tournament design should ensure sufficient attempts for each participant, enabling meaningful skill development while accurately reflecting their skill levels. However, practical constraints on time and cost limit the total number of attempts, making the tournament format design a complex balancing act. This study proposes a new tournament format that addresses these challenges while maintaining fairness and practicality. To achieve this, we analyzed historical data from recent tournament sessions, including the number of attempts and hits for each participant. Using these data, we estimated the probability distribution of the participants' skill parameters (success ratios) and conducted numerical simulations to evaluate various tournament formats. The performance metrics defined by the authors included the total tournament cost (total number of attempts) and ranking estimation accuracy (weighted difference between the true and observed rankings). These metrics were then quantified through numerical simulations based on skill distributions estimated from historical data. Our analysis revealed the following key insights. The current tournament format, while effective in some respects, exhibits substantial variability in the total number of attempts, as indicated by the large standard deviation, which potentially reduces the fairness and educational value of the competition. The number of preliminary attempts will increase from four to six, and the semifinals in the current tournament format will be eliminated. The revised tournament format ensures a higher minimum number of attempts for all participants, a more stable total number of attempts (i.e., a smaller standard deviation), and comparable performance in estimating participants' skill levels. This adjustment ensures that the participants have sufficient opportunities to demonstrate their skills and enhances fairness in competitions while fulfilling their educational objectives. In conclusion, this study highlights the importance of carefully balancing educational, competitive, and practical considerations in the design of sports tournaments, particularly for student-focused events such as Kyudo. Our proposed format not only aligns with the traditional values of Kyudo but also addresses modern constraints, providing a more robust and fairer format for young athletes. Future work will involve extending the proposed framework to optimize formats for other traditional sports and conducting empirical studies to validate the proposed changes in real tournament settings.

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Hierarchical fair draws: a Champions league case study.

by ***Iain Souttar***, Gareth Roberts **CS** SS036

In this talk we will introduce a novel method for producing an unbiased draw in the context of the new UEFA Champions league format, allowing for a variety of physical and computer-based draw mechanisms. The new format, introduced for the first time this year, has succeeded in creating an expanded tournament of 36 teams where fixtures are varied and interest is preserved throughout. This has been achieved through a departure from the traditional round-robin group stage format, to one where team A playing team B and team B playing team C does not imply that team A plays team C. The result is a fixture list allowing for more excitement and jeopardy, held to the last game week, with the performance of teams able to be collated in one single large league table. This change in format, coupled with additional nationality and pot constraints on the fixtures, however, necessarily means that producing a fair and unbiased draw is more difficult. Put simply, the space of possible sets of fixtures is too large and unstructured to be tractable in an analytical or computational sense and can only be explored ad hoc. The method used by UEFA, carried out almost exclusively by computer, produces a valid draw according to the constraints but artificially inflates the probability of certain draws, while reducing the probability of others. Moreover the mechanism lacks the transparency which public draws like this usually provide.

We impose a hierarchical structure allowing for the schedule to be represented in a simple and refined way, reducing– and introducing order to– the space of valid draws while retaining flexibility. Building on our previous work on the World Cup draw (Canadian J. Stat., 2024) this additional structure allows us to devise unbiased mechanisms for producing draws that can be done, at least partially, live and physically with a ball draw. Besides assigning all valid draws equal probability, and thus producing an unbiased draw, we show that our imposed structure has the desirable consequence of avoiding the possibility of mini-leagues in which random subsets of four or more teams play each other, a feature that the current draw mechanism cannot rule out.

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Sports Medicine 1

Fatigue Monitoring as a Tool for Sport Injury Prevention

by ***Serena Pizzocaro***, Renato Baptista, Svonko Galasso, Simone Bettega, Stefano Ramat, Micaela Schmid, Alessandro Marco De Nunzio

CS SM011

Optimising sports performance requires a fine balance between training intensity, recovery, and injury prevention. Muscular fatigue plays a crucial role in sports injury prevention as it impairs muscular activation and balance, increasing the risk of injury. A common, noninvasive method to study muscular fatigue is superficial electromyography (sEMG). However, studying sEMG during dynamic activities, like fast-paced sports, is challenging due to the non-stationary nature of the signal. This work aims to explore the ability of different parameters to assess fatigue progression during a fatiguing protocol based on random changes of direction.

Forty-one physically active adults ($\geq$2 training sessions per week, mean age $\pm$ std. dev: 22.7$\pm$4.7; 7 females) were recruited to participate in the study. After warming up, participants completed a fatiguing protocol alternating running and resting. They ran 150m within a 4$\times$4m square, following a random sequence across different spots marked on the floor. After each run, they rested for 30 seconds. The protocol ended after four 150m runs. The Rate of Perceived Exertion (RPE) was recorded before the protocol and after each run. The participants were equipped with wearable sEMG sensors, which acquired the activity of 5 dominant leg muscles (Biceps Fem., Rectus Fem., Soleus, Vastus Med. and Lat.). Running data was analysed for fatigue assessment while resting activity served as a reference for muscle onset thresholds. After noise removal (bandpass 20-450 Hz), the signal envelope was extracted (rectification + 2 Hz low-pass filter). Envelope peaks were identified, and their amplitude was compared to the average envelope amplitude for each running session, with peaks below this threshold excluded from further analysis. Fatigue-related features were computed around each peak, including Median Frequency, Instantaneous Median Frequency, Sample Entropy (SE), and Permutation Entropy. Since these parameters typically decrease with fatigue, the slope of their linear regression was used to assess fatigue progression

RPE increased progressively for all subjects from pre-protocol (mean: 8.6) to the final run (mean: 16.9), indicating a consistent perceived exertion increase across participants. Among all parameters, the slope of SE exhibited negative values in most cases, indicating the manifestation of fatigue. The most solicited muscle during the protocol was the Vastus Lat., which was fatigued in 94% of the subjects.

While fatigue during dynamic activities has been studied, existing research primarily focuses on controlled, repetitive movements that do not fully capture the complexity of real-world sports scenarios. In contrast, this study aimed to examine fatigue during random changes of direction, a movement pattern more representative of fast-paced sports, where athletes frequently engage in unstructured, reactive motions. This approach showed promising results in utilising Sample Entropy to analyse the manifestation of muscular fatigue and could potentially be developed into real-time fatigue monitoring tools for coaches and trainers, optimising training loads and preventing injuries.

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AI-informed Non-linear Cox Model for Survival Analysis of Running-Related Injuries

by ***Katarzyna Szczerba***, Christophe Ley, Daniel Theisen, Laurent Malisoux **CS** SM012

As awareness grows about the benefits of physical activity, there is an increasing need for advanced tools in sports medicine. Running is one of the most popular form of physical activity, as it can be easily practiced, almost everywhere, with minimal equipment. Despite the health benefits of running, injury risk is high, prompting questions about key risk factors and prevention. A large randomized controlled trial with a 6-month follow-up was conducted in Luxembourg in 2017-2018 in 848 leisure-time runners with the aim to investigate the effect of shoe cushioning on injury risk, as well as to understand the relationship between running biomechanics and injury risk. While prior analyses avoided machine learning due to its 'black box' nature, the preferred Cox model, though interpretable, cannot capture non-linear relationships. Using 10-fold cross-validation with the concordance index as the evaluation metric, we found that a gradient-boosted Cox proportional hazards model with regression trees as base learners outperformed all other models. To build upon this discovery while preserving the interpretability of the traditional Cox model, we propose the AI-informed non-linear Cox Model, where AI (Artificial Intelligence) enhances predictive capabilities. This method uses insights from a highly predictive machine learning model, extracted with an interpretable machine learning tool, to integrate non-linear relationships into the traditional Cox model. We believe that our AI-informed Cox model can become an important new handle for clinicians and sport scientists.

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Moving toward the single-session paradigm for the prevention of running-related injury

by ***Laurent Malisoux***, Jesper Schuster Brandt Frandsen, Adam Hulme, Erik Thorlund Parner, Merete Møller, Ida Lindman, Josefin Abrahamson, Nina Sjørup Simonsen, Julie Sandell Jacobsen, Daniel Ramskov, Michael Bertelsen, Sebastian Skejø, Rasmus Oestergaard Nielsen **CS** SM013

Background: Running “too much” before musculoskeletal structures have adequately developed to withstand the external applied load is recognised as the main reason for injury occurrence. However, the precise calculation of “too much” is subject to considerable debate among sports injury scientists. The most widely used calculations to quantify changes in running distance over time includes the Acute to Chronic Workload Ratio (ACWR) and the week-to-week ratio. The underlying paradigm of these approaches suggests that overuse injuries develop across multiple running sessions (i.e., over the last week). Actually, few runners report symptoms before an injury occurs, suggesting that they may be more vulnerable when increasing distance too rapidly within a single session. This new “single-session paradigm” could provide new insights into the development of overuse injuries. Therefore, the objective of this study was to explore whether a spike in kilometres run during a single session or over a one-week period, compared with the preceding period, was associated with an increased rate of running-related overuse injury. Methods: English-speaking, adult runners, quantifying running distance using wearable training load monitoring devices, were recruited for an 18-month cohort study. Three training-related exposures were defined based on a relative change in running distance: (i) session-specific running distance relative to the longest distance run in the past 30 days; (ii) one-week period relative to the preceding three weeks using the ACWR; (iii) one-week period using a week-to week ratio. Exposures were categorised into one of four time-varying states: (i) regression, or up to 10% increase (reference); (ii) ‘small spike’ between 10% to 30% increase; (iii) ‘moderate spike’ between 30% to 100% increase; and (iv) ‘large spike’ >100% increase. The main outcome measure was a self-reported overuse running-related injury. A cox proportional hazards model with time-varying covariates was used to estimate adjusted hazard rate ratios (HRR), taking right censoring and competing risks into account. Results: Among 5,205 runners (22% female), a total of 1,820 (35%) sustained a running-related injury during 588,071 sessions. Significantly increased rates of running-related overuse injury were identified for small spikes (HRR=1.64 [95%CI: 1.31;2.05, p=0.01]), moderate spikes (HRR=1.52 [95%CI: 1.16;2.00, p<0.01]) and large spikes (HRR=2.28 [95%CI: 1.50;3.48, p<0.01]) in single-session kilometres run. A negative dose-response relationship was observed for the ACWR. No relationship was identified for the week-to-week ratio. Conclusion: A significant dose-response relationship was found between changes in single-session distance and running-related injuries in the largest cohort study conducted to date on the topic. More specifically, the rate of running-related overuse injury was significantly increased when the distance of a single running session exceeded 10% of the longest run undertaken in the last 30 days. Healthcare professionals and coaches are encouraged to adopt this new single-session paradigm and to promote a safer approach to maximal progression in running distance to runners. Conversely, caution is advised when relying on recommended training load calculations such as the ACWR and weekly-gradual changes, as no association between these approaches and injury risk was found.

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Bridging Gaps in Injury Prevention: Insights from National Sports Stakeholders

by ***Aude Aguilaniu***, C. Mouton, C. Tooth, J. Benoit-Piau, J. Pauls, N. Goedert, E. Verhagen, C. Nührenbörger, R. Seil

CS SM014

This study explores perceptions of sports injuries and their prevention among key stakeholders in the national sports community, aiming to identify barriers, and facilitators for implementing effective preventive measures.

Twelve semi-structured interviews (45 minutes each) were conducted with three athletes, three coaches, three healthcare professionals, and three representatives from national sports organizations. Topics explored personal experiences with injuries, injury management, perspectives on prevention, and expectations for improving prevention strategies. Transcriptions were analyzed using grounded theory, allowing iterative data collection and thematic analysis to identify key concepts related to sports injuries and their prevention.

Participants primarily associated sports injuries with the inability to train or compete at full capacity. Pain was commonly viewed as an intrinsic part of sports, with athletes often normalizing and developing coping mechanisms for it, rather than associating it with injury. Coaches and healthcare professionals linked injury prevention to performance, but athletes tended to follow preventive measures only when guided by professionals, often perceiving little immediate benefit. National sports organization representatives emphasized that framing prevention solely around injuries is problematic, advocating for a broader approach that includes enhancing overall health and performance. Barriers to prevention included limited time, inadequate resources, fatigue from repetitive exercises, lack of enjoyment, and the discrepancy between preventive routines and sport-specific needs. Furthermore, poor communication among stakeholders and fragmented organizational structures impeded the implementation of effective programs. Facilitators of prevention included linking it to performance outcomes, integrating enjoyable routines into training, and fostering athlete motivation through tailored, sports-specific strategies.

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The Cognitive Basis of Sport Injuries - Using SKILLCOURT Technology to reduce Injury Risk and support Rehabilitation in Sport

by ***Thorben Hülsdünker***, Andreas Mierau, Lutz Vogt, Winfried Banzer, Bettina Karsten, Florian Giesche, David Friebe, Gülsa Erdogan, Maxime Laporte

CS SM015

Over the last years, the number of injuries in sports have substantially increased. This especially applies to lower extremity injuries as anterior cruciate ligament (ACL) tear. Adequate estimation of injury risk and effective return to sport (RTS) assessments are essential to support injury prevention and avoid-re injury. However, current approaches focus on strength and balance measures while cognitive elements remain largely unconsidered in training, injury prevention and RTS. In highly dynamic ball and team sports, athletes are physically performing in cognitively demanding environments. This results in motor-cognitive interference, where neural resources must be distributed between cognitive and motor processes. Accordingly, injuries are often not due to the athlete's limited strength or motor control quality but the inability to adequately perform the motor task under cognitive load. Assessing motor-cognitive interference must become an integral part of injury risk estimation and RTS procedures. This presentation will provide the neuroscientific background of motor-cognitive interference, outline the importance of integrating cognitive tasks into professional training in sports and elaborate on the three principles of brain training. Focusing on the analysis of novel sport technology, the SKILLCOURT will be introduced. The SKILLCOURT has been developed to integrate combined cognitive and motor training (motor-cognitive training) into training regimes to simulate situations of motor-cognitive interference for training and assessment. The technology uses Lidar sensors and 3D camera including AI-based motion capture to combine motor, physical and cognitive components for improving sport performance and reducing injury risk. Three studies using the SKILLCOURT technology will be discussed. In a first study, using motor-cognitive training revealed better transfer to sport-specific performance in football when compared to a motor training alone. Study 2 suggest that motor-cognitive training can reach high physical intensity which is essential for training in professional sport. The third study supports a higher brain activation in motor-cognitive training when compared to purely brain training on a computer as a potential underlying mechanism of superior training effects in motor-cognitive training. Based on these results, the principle of cognitive load management in professional injury risk assessment and RTS aiming to support injury prevention and improve return to play readiness in professional sport will be introduced. The presentation will provide novel insights into recent developments in sport technology and usage of data for injury risk estimation which will be of high relevance to scientists and practitioners working in sports.

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Sports Analytics 4

Lasso Multinomial Performance Indicators for in-play Basketball Data

by ***Argyro Damoulaki***, Ioannis Ntzoufras, Konstantinos Pelechrinis **CS** SA041

A typical approach to quantify the contribution of each player in basketball uses the plus-minus method. The ratings obtained by such a method are estimated using simple regression models and their regularized variants, with response variable being either the points scored or the point differences. To capture more precisely the effect of each player, detailed possession-based play-by-play data may be used. This is the direction we take in this article, in which we investigate the performance of regularized adjusted plus-minus (RAPM) indicators estimated by different regularized models having as a response the number of points scored in each possession. Therefore, we use possession play-by-play data from all NBA games for the season 2021-22 (322,852 possessions). We initially present simple regression model-based indices starting from the implementation of ridge regression which is the standard technique in the relevant literature. We proceed with the lasso approach which has specific advantages and better performance than ridge regression when compared with selected objective validation criteria. Then, we implement regularized binary and multinomial logistic regression models to obtain more accurate performance indicators since the response is a discrete variable taking values mainly from zero to three. Our final proposal is an improved RAPM measure which is based on the expected points of a multinomial logistic regression model where each player's contribution is weighted by his participation in the team's possessions. The proposed indicator, called weighted expected points (wEPTS), outperforms all other RAPM measures we investigate in this study.

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Evaluating NBA Player Win Contribution with Machine Learning Techniques

by ***Ross Lauterbach***, Dana Sylvan **CS** SA042

This research introduces a novel index to quantify NBA (National Basketball Association) player contributions to team wins using logistic regression and other methods. A model is trained on historical game data to predict wins based on player statistics, establishing an expected win contribution baseline for each player. Variations of the index are generated using Monte Carlo simulations, feature selection, and position-based grouping to refine the model. These approaches are compared based on their alignment with observed outcomes, offering a robust, data-driven metric for player evaluation. The findings provide valuable insights for analysts, coaches, and decision-makers in basketball strategy and performance assessment.

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Team Dynamics and Home Continent Advantage: Europe's Dominance in the Ryder Cup

by ***Justin Ehrlich***, Hunter Geise, Collin Kneiss, and Charlotte Howland **CS** SA043

This study analyzes team dynamics in the Ryder Cup, with the goal of answering three research questions: (1) whether either team exhibits a cohesive, team-level advantage in a fixed-effect manner, where the whole is greater than the sum of its parts, (2) whether individuals on either team consistently overperform or underperform based on marginal Official World Golf Rankings (OWGR) differences, and (3) whether a home-field advantage, defined by the team's continent, significantly influences outcomes. The Ryder Cup, a biennial competition between Europe and the United States, serves as a unique microcosm to examine the interplay between team dynamics, individual ability, and environmental factors.

To investigate these questions, a novel metric called "world golf ability" was developed, which is calculated as the reciprocal of OWGR ranking to give higher weights to top players. When evaluating team-level performance, we determined the median of the teams' participants' world golf ability to mitigate the impact of outliers. This approach emphasizes the importance of team ability in the Ryder Cup, where substantial mismatches play a critical role, but the effect of outliers is minimized. Linear and generalized additive models (GAMs) were estimated to assess the relationships between team ability, home advantage, and point differentials while controlling for individual player ability differences.

The analysis reveals a substantial cohesive advantage for Team Europe. A key finding is that Europe holds an estimated 5.88-point edge over Team USA, even after considering individual player abilities and home-field advantage. This implies that Team Europe gains an advantage due to superior collective dynamics, greater preparation, and/or strategic thinking, which ultimately leads to enhanced overall performance. In contrast, there is no evidence that either team consistently outperforms or underperforms based on individual OWGR rankings, indicating that Ryder Cup results are shaped more by team dynamics than deviations in individual performance.

When analyzing home-field advantage, we found a significant 4.08-point edge for the home team over the away team. This edge was not found to be significantly different for either team. It is likely this advantage is due to crowd support, familiarity with the course type, and the absence of transatlantic travel.

By analyzing the Ryder Cup, this study not only provides insights into one of the most important international team competitions in golf, but also contributes to the field of team dynamics and offers evidence that the makeup and leadership of a team can have a significant impact on its outcome.

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Some alternate scoring systems to a test cricket series

by ***Graham Pollard***, Anthony Bedford, Tristan Barnett **CS** SA044

The relatively high draw probability in test cricket has fluctuated over the years from around 25% in 2003 to around 15% in 2022. These statistics indicate that players are playing more aggressively to score runs to increase their chances of winning the match due to the limited number of overs available to bowl the opposing side out twice to reduce the draw probability, and this strategy inadvertently increases the chances of the opposing side winning since by scoring runs faster there may be an increased chance of losing wickets. The draw probability can be reduced in test cricket by increasing the number of allowable overs, where the current system has a maximum of about 450 overs (90 overs over 5 days). Given that One Day International (ODI) cricket plays a maximum of 100 overs in a day, it could then appear 'practical' to extend the number of overs in test cricket from 90 to 100 overs per day. Also, an additional 6th day could also appear to be a 'practical' strategy to reduce the draw probability. Another method to reduce the draw probability in test cricket is by playing only one innings for each side (compared to the standard two innings). Thus, this presentation will discuss alternate scoring systems with a focus on the one-innings structure to a 3-test and 5-test series based on the discussion above using the following key objectives:

- reduce the draw probability each match
- increase the chances of the stronger team winning each match
- increase the chances of the stronger team winning the series
- reduce the length of the series.

A World Cup and a D/L/S method in test cricket is also proposed based around the one-innings structure. The results obtained could potentially be used by regulators to make informed decisions on test cricket scoring systems.

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Notes

A bivariate extension of the regularised adjusted plus-minus model for Basketball match prediction.

by ***Luca Grassetti***, Valentina Mameli, Michele Lambardi di San Miniato **CS** SA045

Basketball analytics is a relevant topic in the sports analytics literature, with many published papers. Key research areas include player and team performance evaluation, injury prevention, and game strategy assessment. Notwithstanding, the literature regarding predicting basketball match results is limited, and its applications are not widely studied. Predicting outcomes is challenging due to the low signal in the data. For example, in the NBA championship, teams frequently face each other multiple times, resulting in varying outcomes without clear explanations. Moreover, basketball involves alternating possessions and a catch-up restart rule, ensuring a balanced number of possessions between teams. Unlike other ball sports like handball or water polo, basketball has differentiated scoring for each possession, a non-standard measure in literature. Players on the court can be changed without restrictions during game suspensions. Consequently, offensive and defensive strengths depend on the players in play, resulting in significant variability between and within teams. As a result, useful stylised facts cannot be exploited as straightforwardly as in other sports; the typical home advantage cannot be identified, either.

This project aims to develop a prediction model that combines existing soccer match prediction literature, particularly bivariate models for home and away scores, with models for assessing player performance typical in the basketball framework.

From the perspective of game outcomes, the predictive capability of model-based player performance metrics, such as regularised adjusted plus-minus (RAPM), is limited. The bivariate model formulation can improve this aspect, mimicking the standard solutions used to predict match outcomes in other sports, such as soccer, and typically based on a more standardised scoring metric. The development of the proposed model includes two main steps. First, separate models are developed for home and away teams' scores, with each equation affected by the interplay of offensive and defensive players' contributions, as in the RAPM model formulation. Second, the play-by-play data are aggregated over evenly spaced intervals, called rounds, to reduce data heterogeneity. This solution requires that, for each round, the presence of players on the field is evaluated by considering their usage percentage rather than classical indicator variables.

We show that this last modification only slightly affects the results of the original RAPM model but simplifies the bivariate generalisation, making it more usable. The formulated model can accommodate various distributions depending on the rounds' length. The research compares solutions based on Poisson, over- or under-dispersed Poisson, and Gaussian distributions, including their zero-inflated versions if needed. All models are estimated using a Bayesian approach.

NBA data from the 2022-2023 season is analysed to assess the proposal. The findings suggest that bivariate RAPM models benefit from the advantages of model-based approaches regarding player performance, and they can be used to characterise the game's flow better and predict the outcomes of game periods. Notwithstanding, the analyses show that the predictive capability, determined by comparing observed and estimated results of the rounds, is inadequate. Conversely, a superior outcome was obtained by aggregating rounds across games. The models have been evaluated considering different criteria: accuracy and positive and negative predictive values.

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Sports Analytics 5

Predicting the probability of breaking a world record

by ***Michele Lambardi di San Miniato***, Giovanni Fonseca, Federica Giummolè, Valentina Mameli **CS**
SA051

Setting a world record in sports is a consequence of exceptional performance. Then, to describe such events, it is natural to rely on Generalized Extreme Value (GEV) models. In particular, it is of great interest to predict whether a new world record may be observed in the future. We address the problem of computing a reliable probability of breaking the world record in the incoming year. Once a suitable parametric model is defined, the usual way to proceed is to estimate the unknown model parameters using past observations and then compute probabilities using this estimative model as a substitute for the true one. Unfortunately, the uncertainty introduced by substituting the unknown model parameters with their estimates may be substantial, especially for small samples, leading to poor predictive performance. This is the case in sport competitions, where the ability to beat the world record depends on the actual generation of athletes, and, hence, it is realistic to assume that only more recent data bring all the needed predictive information.

In the last 30 years, the problem of improving estimative predictions obtained from small samples has been addressed by introducing improved predictive distributions. Usually, these improvements aim to correct the coverage of predictive quantiles, at least to a high order of approximation. On the other hand, these proposals are unsuitable for predicting probabilities. Recently, Fonseca et al. (2025) defined new predictive distributions that can be applied to obtain appropriate probabilities of breaking a world record. Such proposals fulfil distinct properties of unbiasedness and calibration for probabilities.

In this work, we evaluate and compare the predictive distributions presented in Fonseca et al. (2025) with improved predictive distributions derived using different methods, including asymptotics, bootstrap calibration, fiducial and confidence distribution approaches; see, for instance, the review paper by Tian et al. (2022). In particular, we apply the Gumbel model to annual records data from 2001 to 2024 for different athletic and swim competitions, and we highlight opportunities and problems arising from different approaches to predict the probability of beating a current world record.

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Efficiency of live-betting markets in tennis

by ***Chinmay Divekar***, Rishideep Roy, Soudeep Deb **CS** SA052

Tennis, a globally popular sport, traditionally relied on coach observations and pre-match analysis for player development and performance prediction. While sports analytics has revolutionised many aspects of the game, in-game betting strategies remain largely unexplored. This article attempts to solve this problem and fill the gap in the extant literature, by proposing a Markov Decision Process (MDP) framework that provides real-time betting recommendations during a match. The proposed model assesses the evolving match dynamics and generates recommendations for the bettor after every game of a tennis match. It provides two crucial recommendations: whether to place a bet on any player or to refrain from betting, and the optimal percentage of the available betting capital to wager. This research departs from conventional pre-match betting strategies, which primarily consider factors like player rankings and historical performance. By leveraging live match data, the MDP framework incorporates the fluctuations of each game, offering a more informed and potentially more profitable betting approach. The model's performance is evaluated on a dataset of Women's Tennis Association (WTA) matches. Results demonstrate that the MDP-based strategy outperforms traditional pre-match betting models, highlighting the potential of this novel approach for optimizing in-game betting decisions in professional tennis. This study contributes to the growing field of sports analytics by developing a data-driven framework for within-game betting in tennis. The findings have implications for both professional bettors and sports enthusiasts seeking to enhance their understanding and engagement with the game.

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Performance Evaluation and Ranking of Drivers in Multiple Motorsports Using Massey's Method

by ***Ryoga Yamaguchi***, Ryoga Yamaguchi, Eiji Konaka **CS** SA053

In four-wheeled motorsports, various championships, such as Formula 1 (F1), the World Endurance Championship (WEC), and Super GT, are organized globally. While these championships have significant differences in vehicles used and the regulations applied, they share the common characteristic of employing four-wheeled cars. These characteristics allow drivers to compete within the same championship, participate in multiple series simultaneously, or transfer to entirely different championships. Furthermore, participation in F1 requires a Super License, and some championships outside of F1 award Super License points to drivers for obtaining this license. Despite these connections and hierarchical relationships between championships -such as drivers participating across different championships and the Super License system itself- there is no official ranking system for drivers across multiple championships. In addition, the authors' investigation found no existing studies that use validated rating methods across various championships to evaluate the performance of drivers.

This study aims to develop a method for quantitatively evaluating the achievements of all drivers who have participated in multiple championships, using Massey's rating method, a well-known quantitative performance evaluation approach. As a result, the study tries to establish a unified ranking system of drivers in a wide range of four-wheeled motorsports championships.

In order to assess the performance of each driver, it is necessary to compare the results of individual drivers and compute evaluation values by using drivers who have participated in multiple championships as a reference point. For this purpose, the evaluation methodology is based on Massey's rating method. This rating method is commonly applied in sports where two competitors compete against each other for scores. It assumes that the difference in the rating values between players explains the score difference of one match, and then estimates the rating value of every player based on the match results using the least squares method.

In this study, Massey's method is extended to ranking-based race competitions by replacing the score difference with the logarithmic difference in race positions. The resulting ratings can be interpreted as performance evaluation values for the drivers.

Data has been collected from championships involving formula cars in Europe, Japan, and the United States to calculate the performance evaluation values. Eight series were analyzed: Formula 1, Formula 2, Formula 3, Formula E, Super Formula, Super Formula Lights, IndyCar, and IndyCar Lights. The data collection spanned three years, from 2021 to 2023, encompassing 275 drivers.

Using this method, we calculated the performance evaluation values of drivers participating in these championships. The results revealed performance evaluation values that reflect hierarchical relationships between championships. Additionally, in championships such as F1, where competition in vehicle development plays a significant role and dominance tends to persist, the drivers with consecutive victories were to have exceptionally high-performance evaluation values. Future work is focusing on analyzing the transitions in performance evaluation values for individual drivers to validate the predictive accuracy.

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Comparison of Rectangular and Hexagonal Grids for Spatial Analysis of Target Regions in NFL Passing Plays

by ***Matthias Schilling***, Maximilian Moll, Stefan Pickl **CS** SA054

The growing amount of data and computational resources has allowed rapid developments in many areas, including professional sports. Data-driven analytics has been increasingly integrated to gain a competitive advantage, with the automated tracking of player and ball positions multiple times each second facilitating the application of sophisticated algorithms to improve the understanding of player and team performance. The amount and complexity of underlying processes requires efficient data representations. In order to identify safe target regions for passing plays of the 2018 NFL regular season, an aggregation of different regions is required. Calculating aggregations of arbitrarily shaped regions is computationally expensive, but can be implemented more efficiently as set operations when using a grid representation. A comparative analysis of hexagonal grids, rectangular grids and a numerical approach provides further insights, highlighting the advantages of hexagonal grids in spatial efficiency and computational performance. First promising results will be presented.

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Notes

Tennis model in betting: Grand Slam analysis

by ***Rita Norbutaitė***, Martynas Manstavičius **CS** SA055

Tennis is a racket sport played in a rectangular area, called court, by individual players (singles) on each side or teams of two players (doubles). Due its hierarchical complexity, tennis is a widely analyzed sport in mathematics and there are many ways to predict tennis matches. Talking from bookmakers side it is important to find the most reliable model to maximize profit and minimize risk. For this purpose we applied both investors and actuarial approaches to the selected tennis mathematical model to evaluate expected profit and risk. For our analysis, we used data of Grand Slam (Australian Open, Roland Garros, US Open, and Wimbledon) tournaments. We predicted the results of the tournaments in 2024 using data of each tournament qualification and past years' performance. Using different betting techniques and several different model parameters we predicted bookmaker's expected profit, risk and ruin probability.

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Sports Medicine 2

Predicting Injury and Career Longevity in Baseball Pitchers Using Workload Metrics and Biomechanical Data

*by **Lorena Martin*** **CS** SM022

Injury prevention and career longevity are critical concerns in professional baseball, particularly for pitchers, whose workload management significantly impacts their performance and durability. This study leverages publicly available Key Performance Indicators (KPIs) from FanGraphs and Baseball Reference to develop predictive models for assessing injury risk and career length in Major League Baseball (MLB) pitchers. Using historical player statistics, pitch-level data, and injury reports, we analyze workload-related variables such as total pitch count, innings pitched (IP), pitches per start, fastball velocity (FBv), average spin rate, release extension, pitch type frequency (e.g., fastball vs. breaking balls), arm slot consistency, and effective velocity. Additionally, we incorporate the Acute to Chronic Workload Ratio (ACWR) to quantify short-term workload spikes relative to long-term conditioning, providing a dynamic indicator of injury risk due to overuse and fatigue accumulation.

To predict injury risk and career longevity, we apply a multi-method modeling approach, integrating regression models, Random Forest, and Gradient Boosting to estimate workload thresholds that influence durability. Additionally, clustering techniques such as K-Means and Hierarchical Clustering help identify distinct pitcher workload profiles and categorize athletes based on their risk levels. By leveraging these models, we aim to provide actionable insights for teams, coaches, and medical staff in optimizing workload strategies, improving player health, and extending career longevity.

This study presents a scalable, data-driven approach to injury risk assessment and workload optimization, contributing to evidence-based decision-making in pitcher development and management.

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Wearable Sensor Monitoring of Walking on Different Surfaces as a Digital Outcome: Deep Learning Model Performance with Sensor and Class Reduction

by ***Gabriella Vinco***, Oussama Jlassi, Christophe Ley, Phil Dixon, Frederic Garcia, Bernd Grimm **CS** SM023

Wearable technology is increasingly used in sports medicine for remote monitoring of walking behavior, such as tracking step counts. While basic step counts offer some insight, they lack the contextual information needed to effectively assess athletes recovering from injury or surgery. More meaningful analysis involves evaluating step patterns on specific surfaces, like stairs or slopes, to gauge rehabilitation progress and customize training and recovery plans. Although algorithms exist to classify walking surfaces using inertial measurement unit (IMU) signals, the absence of standardized and user-friendly methods for IMU data collection and analysis has limited the development of reliable, widely applicable models. This study explores whether simplifying IMU-based gait analysis through deep learning (DL) models—by reducing the number of sensors or grouping surface classes—can maintain or enhance classification accuracy, ultimately improving real-world applicability in sports rehabilitation.

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What is chronic load? Exploring different definitions of the chronic load in relation to running-related injuries

by ***Sebastian Dyrup Skejø***, Jesper Schuster Frandsen, Rasmus Østergaard Nielsen **CS** SM024

Running-related injuries are common and are typically attributed to training loads exceeding the capacity of the body to withstand that load. Recently, we have proposed a new method for operationalizing the relationship between training load and capacity – the single-session spike method. This method compares the training load within a single session to the training load over a preceding period containing multiple training sessions – the latter often being defined as the chronic load. Given the chronic load represents multiple training sessions, it is often necessary to combine the chronic training loads into a single number. Here, we explored how different definitions of the chronic load affected the estimates of injury risk using the single-session spike method.

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Modeling the evolution of athletic abilities in young elite soccer players considering injury history

by ***Arthur Guillotel***, Brigitte Gelein, Rufin Boumpoutou, Benoit Bideau and Anthony Sorel **CS** SM025

While previous studies, starting with Moore, have modeled age-performance relationships, individual variability often limits precision. Mixed Models (MM) have recently started to be successfully used to address this limitation. However, their application to performance in team sports remains unexplored, and the impact of injury history has traditionally been overlooked. The use of non-parametric modeling for estimating fixed effects has been explored in statistical research, but its application to sport-related studies remains absent.

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Sports Economics 1

A statistical view on xG and GAX

by ***Robert Bajons***, Lucas Kook **CS** SEO11

Expected Goals (xG) are the output of a statistical model assigning a prob- ability of success to a shot using shot-specific covariates and are one of the most popular metrics in modern football (soccer) analytics. Popular xG models are based on flexible machine learning algorithms, such as extreme gradient boosting machines, that account for non-linear and interaction effects of the shot-specific covariates. As a measure of a shot's value, it is commonly used to evaluate the shooting skills of players by considering goals over expectation (GAX), i.e., the difference between actual and expected goals for each shot. However, GAX is often criticized for being unstable over seasons and for not providing (direct) means of uncertainty quantification. In this work, we address both issues by showing how the player-specific GAX relates to a score test when the xG model is a logistic regression and using a nonparametric extension which can be based on any xG model derived from sufficiently powerful machine learning algorithms. The proposed test is based on the Generalised Covariance Measure, which requires an additional regression of predicting which player shot. Under rate conditions similar to double machine learning, the test controls the type I error of falsely rejecting the hypothesis that a player significantly alters the outcome a the shot. Thus, we are able to leverage commonly used black-box xG models, while still obtaining valid statistical inferences on the player-specific odds (or probability) of scoring a goal. Moreover, in order to make the results more interpretable, we show how the proposed procedure relates to player-specific effect estimates in a partially linear logistic regression model of additive effects on the log-odds of scoring a goal from a shot. Finally, we apply our framework to the 2015/16 season of the top five European leagues, determine the best shooters, and compare results across state-of-the-art xG models.

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Sentiment Dynamics in (Social) Media Coverage of the Olympics and Paralympics Across Five Cycles

by ***Maria Amaro***, Roland Molontay **CS** SE012

The Summer Olympics and Paralympics are both classified as mega sports events, yet they differ significantly in media representation and public engagement. This study examines sentiment dynamics and media coverage across five Olympic cycles (Beijing 2008 to Paris 2024), addressing two key research questions: (1) How have public sentiment and media coverage of the Olympics evolved over time, and how do they influence social media discourse? (2) What are the disparities in media attention and sentiment between the Olympics and Paralympics?

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Balancing Olympic broadcasts and viewer demand: an empirical analysis of Belgian TV audiences

by ***Daam Van Reeth*** **CS** SEO13

The Olympic Games represent the biggest sports event in the world. The inclusion of parallel competitions for men and women is one of the appealing features of the Games. Many studies have therefore used the case of the Olympic Games to analyse gender balance in media coverage of sport. Generally, these studies conclude that although gender balance has improved significantly over time, male athletes are still favoured by the media.

Almost all of the studies on gender balance in sports coverage focus exclusively on the supply side of the media market, by measuring how much time TV channels or how much space newspapers dedicate to the coverage of competitions of both sexes. Our study is different and original in its approach because it also uses data on TV audiences, the revealed demand side of the market. This creates an opportunity to examine evidence of disequilibrium between the supply of Olympic TV broadcasts (input market) and the TV demand revealed by sports consumers (output market). More precisely, by using TV audience data we are able to analyse if the observed preference of TV channels for broadcasts of male Olympic competitions is properly reflected in the preferences of TV viewers.

The empirical analysis is based on a comprehensive dataset of all Olympic broadcasts in Belgium for the Olympic Games of London, Rio, Tokyo, and Paris. The data were provided by CIM (Centrum voor Informatie over de Media), Belgium's official audience measurement company. Since we have separate data for both Flanders and Wallonia, we can also examine any differences between Flemish and Walloon viewership of the Olympic Games.

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Sports meet sharing economy: Acceptance of equipment rentals platforms

by ***Milica Maričić***, Nikola Drinjak, Teodora Rajković **CS** SE014

The sharing economy (SE) is an economic model that facilitates peer-to-peer (P2P) transactions through digital platforms, enabling individuals to temporarily exchange, rent, or share underutilised assets or services for monetary or non-monetary compensation. Three core participants or elements in the concept are the users (those seeking resource), the platform which facilitates transactions securely and efficiently, and the providers (those offering resource). The SE has been praised for moving the focus from ownership to re-use and multiple usage of scarce resources, improving environmental consciousness, allowing individuals to be economically active and make additional income, as well for creating new products and services. So far SE has disrupted the hospitality (Airbnb) and transportation industry (Uber), freelancing (Upwork), project funding (Kickstarter) and other industries. For the sports and sports activities sector the SE provides compelling opportunities for innovation. There are multiple ways how SE could transform this sector, allowing P2P equipment rentals, transforming empty stadiums into community spaces, crowdsourcing for amateur sports venues to matching coaches with local athletes. Good examples of sharing platforms in the sport sector are Equip Sport, Spinlister, CoachUp and TrainHeroic. This paper has the goal to explore the acceptance of equipment rentals platforms in a developing country, Republic of Serbia. Previous research showed that the sharing economy market in Serbia is slowly but surely developing and that the acceptance and usage of shared accommodation and shared transportation platforms improved since 2020. To the knowledge of authors, currently, there is no P2P or company-owned equipment rental platform operating in Serbia. The research methodology will encompass a literature review on the currently operating platforms in P2P equipment rentals platforms and their business models. Taking into account the specificities of the sharing model and platforms, the UTAUT (unified theory of acceptance and use of technology) model questionnaire will be modified. The survey will be conducted in the capital of Serbia, city of Belgrade using convenience sampling. To verify the conceptual model structural equation modelling (SEM) will be used. This study has a two-fold goal. First, to quantify the interest of individuals in Belgrade, Serbia to use P2P sport equipment renting platforms and examine how Performance expectancy (PE), Effort expectancy (EE), Social influence (SI), and Facilitating conditions (FC) impact Behavioural intention (BI). These results could be valuable to individuals and organisations interested in creating a startup in the sector or those already in the sector who are considering entering the Serbian market. By understanding these factors, stakeholders can better address potential barriers to adoption and optimise their service offerings for the local market. The second goal is to raise awareness among individuals that sport equipment sharing platforms exist as a viable service which can reduce financial barriers to sport participation, promote sustainability through resource sharing, and create additional income opportunities for equipment owners. This research will contribute to the growing body of literature on the sharing economy models and platforms in the Balkan region, where such platforms are still in their early stages of development and acceptance.

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Sports Analytics 6

The Right Way to Synchronize Tracking and Event Data: Using Domain Knowledge to Optimize Algorithms

by ***G.A. Oonk***, D. Grob, M. Kempe **CS** SA061

In soccer, event and tracking data are used to analyze individual and team performance. Event data captures the type of event (e.g., pass or shot) and which player is involved. Tracking data captures the location of all players and the ball over time at ≈25 frames per second. Although these separate data sources provide interesting insights, combining the two captures the dynamics of the game more completely and allows for the training of complex (machine learning) models. For example, tracking data features have improved the performance of expected goal models, and the decision-making of players could be assessed by estimating all passing options of a player and analyzing the risk-reward trade-off between all options. The added value of combining tracking and event data is widely recognized. However, how the data should be synchronized is often overlooked. The timestamps between the tracking and event data are poorly aligned since, among others, human error is introduced in the data collection of event data. Poor synchronization introduces avoidable noise into the features and variables, affecting the outcomes of statistical and machine-learning models. Since an offset of as second could mean that the ball is already in the goal when trying to evaluate a shot, synchronization a serious problem to consider. The most common method for synchronizing tracking and event data involves using cost functions for each event. However, this ignores the order of the events as found in the event data and thus results in insufficient synchronization quality, especially in chaotic match situations. To solve this problem, the Needleman-Wunch algorithm was proposed. The algorithm was originally developed for bioinformatics to align two amino-acid strings but showed to be useful for aligning other types of data as well. However, keeping the event order in place comes at a computational cost since the Needleman-Wunch algorithm scales as $O(m \cdot n)$, compared with $O(n)$ for using cost functions. For this reason, the Needleman-Wunch algorithm has been largely ignored for synchronizing tracking and event data. We aim to implement the Needleman-Wunch algorithm that is optimized to synchronize tracking and event data. We exploit domain knowledge and information from the tracking and event data, such as when the ball is in and out of play, resulting in a 70-fold time reduction to synchronize a single match. By optimizing the Needleman-Wunch algorithm we get a training-free, high-quality synchronization algorithm, with low computational cost. Using data from seven open-sourced matches of the German Bundesliga, we show that the median difference between synchronization with the Needleman-Wunch approach and using timestamps is 0.64 seconds, with a third of the events being more than 1 second off. Besides a general explanation of the Needleman-Wunch algorithm and the applied optimizations, we show the misalignment between tracking and event data and practical examples of the importance of proper synchronization using DataBallPy.

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Notes

Detecting Movement Patterns That Lead To Poor Performance With Sportlets

by ***Gayatri Chakkithara***, Gayatri Chakkithara, Rahul Selvakumar **CS** SA062

This analysis examines the role of the primary upper kinetic chain in basketball free-throw performance by analyzing movement patterns. We identify distinct sub-movements that significantly impact shot accuracy and consistency. Using multivariate shapelet analysis, we reconstruct these sub-movements across the kinetic chain, revealing patterns that correlate with both successful and missed shots. This method provides insights into the biomechanical factors influencing shot outcomes, enhancing understanding of the components critical for optimal shooting performance. By pinpointing motion sequences that contribute to poor performance, our findings help coaches and athletes target areas for improvement.

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Quarterly Changes in Player Movement and Positional Dispersion in NBA Games

*by **Chuqi Chen***, Arnold Baca, Juliana Exel **CS** SA064

This study investigates how player movement dynamics, such as action zones and positional dispersion, change throughout basketball games, using tracking data from 42 NBA games. The results show that the fourth quarter has significantly larger action zones ($132.63 \pm 23.94m^2$) compared to the first quarter ($128.07 \pm 24.99m^2$, $\chi^2(3, N = 840) = 8.32$, $p = 0.04$), with positional dispersion also being significantly higher in the second half compared to the first half (0.740 ± 0.275 vs 0.638 ± 0.305, $z = -2.30$, $p = 0.022$). These findings highlight the importance of strategic adjustments in the game's later stages.

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Ranking algorithms for games with multilevel results

by ***Leszek Szczecinski*** **CS** SA065

In this work, we discuss the algorithms for ranking in multilevel games (i.e., that have more than two possible outcomes) from two points of view. The first one, called a practitioner's perspective, extends the well-known Elo ranking algorithm by keeping the concept of expected score and attributing different score values to each of the possible outcomes. This is a simple approach (i.e., easy to apply in practice), but, lacking the prediction probabilistic model, it makes it difficult to formally evaluate the algorithms.

On the other hand, the second point of view, we dub the statistician's perspective, starts with a formal probabilistic model and derives the ranking algorithm by optimizing the well-known criteria (e.g. applying the maximum-likelihood principle). The downside is that the resulting algorithm may be difficult to interpret in simple terms.

The objective of this work is to show how these two perspectives can be analytically reconciled and how the ranking algorithm parameters should be chosen. We illustrate the analysis using the results of the volleyball games.

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Sports Medicine 3

The meniscus injury pattern varies with the type of sports in primary ACL reconstructed knees in non-professional athletes.

by ***Caroline Mouton***, Julie Seil, Felix Hoffmann, Romain Seil **CS** SM031

Meniscus injury pattern varies with the type of sports in primary ACL reconstructed knees in non-professional athletes. Overall, the prevalence of MM or LM tears was similar between the different activities at injury. A higher prevalence of BM tears was observed in football compared to winter sports and a higher prevalence of LMPRTs was observed in handball compared to winter sports. These findings may be helpful for future studies analyzing the association between meniscus injury pattern and ACL injury mechanisms.

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Notes

Model-based analysis of the Eurobarometer Survey on Sport participation and Engagement in Physical Activity

by ***Rosaria Simone*** **CS** SM032

From the first 2002 edition, the European Commission carries out periodically the special Eurobarometer survey on sport and physical activity (https://europa.eu/eurobarometer/surveys/detail/2164) in order to assess participation in sport and engagement in physical activity across countries, as well as to understand motivation and barriers towards an active life style. With reference to the 2017 edition, it turns out that the level of participation overall decreased from the 2013 survey, with the exception of few countries (Belgium, Luxembourg, Cyprus, Malta, Finland and Bulgaria) and despite all promotion efforts made by policy makers. The latest results issued in 2022 revealed that sport engagement is remained almost unchanged from the previous wave. These statements are based on the responses on an (ordered) scale with m=6 categories: 1 = Never, 2 = Less often, 3 = 1 to 3 times per month, 4 = 1 to 2 times per week, 5 = 3 to 4 times a week, 6 = 5 times a week or more., to the following questions:

- QB1: How often do you exercise or play sport? (By "exercise"' we mean any form of physical activity which you do in a sport context or sport-related setting, such as swimming, training in a fitness centre or a sport club, running in the park).

- QB2: And how often do you engage in other physical activity such as cycling from one place to another, dancing, gardening, etc.? (By "other physical activity" we mean physical activity for recreational or non-sport-related reasons).

As a matter of fact, statistical statements on these data (aggregated on country basis) are limited to comparisons of relative frequencies and modal values, practice that can be belittling. Indeed, response distributions to QB1 and QB2 present some structural features and appears like a mixture of a distribution characterized by an inflated frequency of responses anchored to the 'Never' category, corresponding to the inactive group of people, and the second characterized by intermediate responses floating between the endpoints of the response scale. Ideally, a third mixture component could occur with modal value at the last category, corresponding to respondents with very active lifestyle. These patterns characterize the distributions of all countries, yet to a diversified extent. In general, polarization and floation of ordinal responses in not unfrequent, and their analysis should be adressed with suitable statistical methods. In this regard, modeling on the discrete scale allows to parameterize these structural features with easy-to-interpret measures, enhancing comparisons across times and countries. The contribution shows the performance of a suitable specification of mixtures of discretized beta distributions to boost the potential of such data in supporting policy-makers to assess the degree by which engagement in sports and physical activities are spread within the population.

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A Bayesian Network Model to Monitor the Risk of Overreaching and Overtraining

by ***Barbaros Yet***, Elif Yılmaz, Ecem Açıkgöz, Naz Dündar, Mustafa Söğüt **CS** SM033

Data-driven athlete monitoring is crucial for planning for more effective trainings and reducing the risk of injuries for athletes. We present a Bayesian Network (BN) model to provide decision support for athlete monitoring. The BN model has been developed by using a combination of domain knowledge and training data. It aims to predict the risk of overreaching and overtraining by using a combination of self-reported internal load inputs that are collected at the end of each training session, and objective measures of fitness and fatigue that are collected at each training microcycle. The BN model also estimates the degree of monotonicity, acute and chronic load. Since BNs are probabilistic models, the athlete monitoring model is naturally capable of handling missing inputs and reason under uncertainty. We present the initial results of applying the BN model to monitor the trainings of two Olympic team sports.

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Notes

Fueling Excellence: The Integral Role of Sport Nutrition Services in a High-Performance Institute.

by ***Myriam Jacobs***, Alwin De Prins, Stéphanie Rosquin, Tammy Diderich, Christian Nührenbörger, Caroline Mouton, Axel Urhausen, Romain Seil

CS SM034

The crucial role of nutrition in injury and illness prevention is well-established, in a challenging context where physical and mental demands of high-performance athletes (HPA) require the support of specialized staff. Sports dietitians aim to deliver evidence-based nutritional guidance promoting both health and performance of athletes. The purpose of this presentation will be to expose specialized sports nutrition services (SNS) to a sports medicine public in a newly created High Performance Institute in a small country. Their definition of primary roles, their implementation and figures on adherence by HPA will be analyzed. The working hypothesis was that the latter will be high once integration and definition of primary roles will be established.

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Notes

Informed Injury Prediction in Elite Football: Decision Theory meets Machine Learning

by ***Manuel Huth***, Jan Hasenauer, Juan Ramón González **CS** SM035

Injuries in elite sports disrupt team performance, shorten careers, and incur significant financial costs. Existing machine learning approaches to injury prediction fail to account for cumulative risk, overlook injury severity, lack reliable probability calibration, and omit statistically guided decision thresholds. Here, we present a novel injury prediction pipeline integrating risk accumulation via time-to-injury-based machine learning, probability beta calibration, and statistical decision theory. Using a unique dataset spanning four seasons from a top-tier women's football team, we demonstrate that our pipeline outperforms standard classifiers, yielding superior discrimination ability. Our framework identifies fatigue as a key injury predictor and incorporates flexible thresholds based on match importance and decision-maker certainty, improving player availability. Scalable, adaptable, and transferable to other sports, this pipeline bridges academic research and practical deployment, empowering sports organizations to optimize player performance and long-term outcomes.

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Sports Analytics 7

Acute effect of running retraining interventions on high-frequency signals of impact variables.

by ***Guillaume Abran***, Kevin Gramage, François Delvaux,Jean-Louis Croisier, Cédric Schwartz **CS** SA071

In a recent randomised controlled trial, impact variables measured in frequency-domain analyses were associated with running-related injuries, whereas impact variables measured in time-domain analyses were not. Although the reduction of impact variables measured in time-domain analyses induced by running retraining interventions is already known, their effect on impact variables in frequency-domain analyses is still unexplored. This study aimed to explore the effect of running retraining interventions on high-frequency signals of impact variables during running.

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Enhancing Football Refereeing with AI: VARS and X-VARS for Assisted Decision-Making

by ***Jan Held***, Marc Van Droogenbroeck, Anthony Cioppa, Sivlio Giancola, Umang Bhatt, Katherine M. Collins, Elaf Almahmoud

CS SA072

The Video Assistant Referee (VAR) has revolutionized association football, enabling referees to review incidents on the pitch, make informed decisions, and improve fairness during the game. However, due to the lack of referees in many countries and the high cost of the VAR infrastructure, only professional leagues can currently benefit from it. To address these challenges, we introduced the Video Assistant Referee System (VARS), an automated solution for soccer decision-making using broadcast cameras. VARS was built upon the latest advancements in multi-view video analysis to provide real-time feedback to referees, helping them make informed decisions that can impact the outcome of a game. While VARS effectively automates decision-making, it does not provide explanations for its decisions, making it difficult to interpret or trust its reasoning. To address this, we later introduced the eXplainable Video Assistant Referee System (X-VARS), a multi-modal large language model trained to analyze football videos from a referee's perspective. X-VARS can perform a wide range of tasks, including video description, question answering, action recognition, and conducting meaningful conversations based on football video content—all in accordance with the Laws of the Game for football referees. To validate our VARS and X-VARS, we introduced two datasets. The first one, SoccerNet-MVFoul, is a video dataset of soccer fouls captured from multiple camera views, annotated with extensive foul descriptions by a professional soccer referee. Using this dataset, we benchmarked VARS to automatically determine whether an action constitutes a foul, assess the severity of a foul, and classify the type of foul (e.g., a tackle, holding, etc.). The second one, SoccerNet-XFoul, is a dataset of over 22,000 video-question-answer triplets annotated by more than 70 experienced football referees. In this abstract, we present the results of a human study exploring the dynamics of when to provide VARS assistance to referee. We investigate how referees' behavior and performance vary across four conditions: (1) no VARS assistance, (2) always VARS assistance, (3) VARS assistance provided only when the model is confident, and (4) VARS assistance available upon referee request. Each condition involved 20 referees, who evaluated 25 multi-view videos of the same football action captured from three perspectives. For each video, referees were tasked with determining whether a foul occurred and, if so, assessing its severity. Our results demonstrate that referees supported by VARS are significantly more accurate, quicker, and more confident in their decisions compared to referees making decisions independently. Additionally, referees have a statistically higher inter-rater agreement with VARS as support. These findings suggest that integrating AI assistance not only enhances individual referee performance but also promotes greater consistency in decision-making across referees. In summary, we showed that VARS and X-VARS have the potential to significantly improve soccer refereeing by ensuring fairness and accuracy across all levels of play. VARS provides a reliable assistant in the decision-making process, while X-VARS demonstrates exceptional capabilities in explaining its decisions, paving the way for enhanced transparency and trust in football refereeing.

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Consideration of Transition Probability Matrices in Markov Models: Applications to Baseball and Soccer

by ***Nobuyoshi Hirotsu***, Nobuyoshi Hirotsu **CS** SA073

The Markov model is a fundamental analytical tool widely applied in game analysis. This study examines the structure and properties of transition probability matrices in Markov models, with a particular focus on their applications to baseball and soccer. Utilizing z-transformation, we analytically investigate state transitions and their transient characteristics in both sports. In baseball, a recent trend has emerged in which the most proficient hitter is positioned around the second spot in the batting order. This study analyzes the impact of different batting orders on the expected number of runs scored during a game by examining transient states using z-transformation. Our findings provide insights into optimal batting order configurations. For soccer, we employ a model that defines states by dividing the pitch into distinct zones and analyze the transient effects of state transitions. Through the examination of transition probability matrices, this study seeks to enhance our understanding of game dynamics. The findings may offer valuable support to analysts in developing game strategies based on probabilistic modeling.

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Identifying Extreme Representative Tennis Players and Match External Load in Grand Slam Tournaments Using Clustering and Archetypoid Analysis

by ***Daniel Fernández***, Quim Brich, Martí Casals, Jordi Cortés, Ernest Baiget **CS** SA074

Unsupervised learning techniques, such as clustering and Archetypoid Analysis (ADA), play a crucial role in sports analytics by identifying distinct profiles and extreme representatives within a dataset. Clustering is widely used to detect underlying patterns, while ADA provides a more refined identification of extreme archetypal profiles. These methods are particularly valuable in sports science, where understanding performance variability is key to optimizing training and competition strategies. In professional tennis, external load demands vary significantly across players and match conditions. Factors such as rally length, movement intensity, and shot frequency influence match dynamics and player workload. Our goal is to identify match patterns and extreme player profiles for tailoring performance strategies and recovery protocols. Our research applies clustering and ADA to analyze external load demands in Grand Slam tournaments, considering key performance variables related to volume, intensity, and efficiency of play at both match and player levels. Using data from 282 matches from the 2017 Grand Slams, we explore match characteristics based on total points played, distance covered, shot count, hitting frequency, average running speed, serve velocity, and the percentage of successful serves. Based on our analysis, we identified four distinct match profiles and four extreme representative player archetypes in male Grand Slam tournaments. The match profiles range from low-intensity encounters (typically on grass courts) to high-intensity, high-volume matches (more frequent on hard courts). Meanwhile, ADA identifies contrasting player styles, from high-volume, defensive-oriented players to low-volume, aggressive players with high efficiency. These findings offer practical insights into performance optimization, injury prevention, and individualized training approaches in professional tennis. Moreover, this study highlights the potential of machine learning techniques, such as archetypoid analysis, to provide nuanced insights into performance demands. Future research could expand on this framework by incorporating recent tournaments and additional contextual factors to refine our understanding of match and player dynamics.

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Implicit Centipedes, or Do the Racers Compete Strategically?

by ***Dmitry Dagaev***, Dmitry Dagaev, Daniil Starikov, Gleb Vasiliev **CS** SA075

The centipede game is a nice illustration of a strategic interaction where the real-world players typically deviate from a subgame perfect Nash equilibrium. In previous laboratory experiments, the participants usually observed the tree of the centipede game, including the payoffs. Even in such rather simple conditions, mental capacity is linked to following the equilibrium path. More advanced players exploit the suboptimal strategies of less advanced ones (Palacios-Huerta and Volij, 2009). However, observing an explicitly defined game could be a crucial factor leading to such an outcome. Consider a more complex implicitly formulated game which is a de facto centipede game. On the one hand, more advanced players can perform even better in implicit centipedes by benefiting from deriving the real structure of the game. On the other hand, if the game is too complex to solve even for the best players, the players may engage into a completely different interaction with an unpredictable outcome. In order to investigate the properties of implicitly formulated games, we consider an antagonistic variant of the centipede game which is eventually played by professional athletes, Formula 1 drivers, and their teams during each race. When two drivers are close to each other, they engage in a game where the goal is to finish in front of the opponent. On each lap, each driver, the leader and the pursuer, decide sequentially whether to go for a pit stop and change the tire. Using the intra-race dataset from several Formula 1 seasons, we show that this complex strategic interaction is indeed a centipede-like game. Despite the implicit nature of the game, we show that better racers and their teams choose strategies that are closer to the predicted equilibrium.

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Sports Analytics 8

Multisport YODA: Leveraging LLMs for Cognition Based Comprehensive Performance Analytics

by ***Sadanand Venkataraman***, Sadanand Venkataraman, Sundharakumar KB, Bharathi Malakreddy A, Santhi Natarajan, Hema A Murthy

CS SA081

In the ever-evolving world of sports, mental and cognitive aspects often dictate the fine margins between victory and defeat. Building on our previous work with Your Offence and Defence Analysis (YODA)—a psychometric tool originally designed for football—we introduce a novel approach that repositions YODA as a system capable of understanding and adapting to multiple sports, by harnessing two distinct Large Language Model (LLM) components in tandem with expert feedback.

The core of YODA lies in mapping a set of primary traits and derived sub-traits, through simulated match scenarios. In its original form, these scenarios were specifically calibrated for football, focusing on elements such as ball control, positional awareness, and decision-making under pressure. To expand YODA's applicability, we employ an LLM-based scenario adaptation module that reformulates each original football-centric prompt into situations appropriate for other team sports. In our initial pilot, cricket is chosen as the exemplar due to its unique tactical depth and different participant roles (e.g., batting, bowling, fielding). The LLM systematically replaces football-relevant elements—such as "offside traps" or "heading the ball"—with cricket-specific references like "running between the wickets" or "field placement," while preserving the underlying cognitive demands.

To ensure that these newly generated prompts retain contextual accuracy and authenticity, subject-matter experts (cricket coaches and sports psychologists) serve as a human-in-the-loop checkpoint. Their reviews guide any necessary refinements to the LLM outputs, confirming that the adapted scenarios remain faithful to the real-world pressures and strategies encountered in cricket.

After finalizing each scenario, YODA's second LLM component comes into play: an auto-scoring engine that interprets participant responses and quantifies cognitive traits in near real-time. Concurrently, experienced coaches perform their own manual evaluations of the same responses. By comparing the automated output against human expert assessments, we assess the reliability and robustness of YODA's cross-sport adaptation. A strong alignment between the LLM-derived scores and the coaches' evaluations would suggest that the adaptation process and automated scoring collectively validate YODA's capability to function consistently across various sporting domains.

Looking ahead, we plan to expand the scope of this pilot study to include additional sports, such as hockey and basketball, and to incorporate real-time match data for a deeper, more dynamic understanding of player cognition. Furthermore, we aim to incorporate real-time performance metrics—such as match statistics or wearable sensor data—to deepen the link between cognitive traits and on-field outcomes. Ultimately, we envision a comprehensive, data-informed system that simplifies the process of psychometric scenario generation, reduces the dependence on single-sport frameworks, and accelerates the adoption of mental performance analytics across multiple athletic domains.

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Models for prediction and analysis in horseracing

by ***Anthony Bedford***, Erica Mealy, Abigail Koay **CS** SA082

In our previous work (Bedford et.al 2024) we presented our computer vision (CV) platform that swiftly extracted horses from vision as analysable objects using segmentation modelling from semi-live footage. Building upon uses of CV and AI through pre-race training, in-race tracking, and post-race adjudication and performance analysis, we propose two methods to obtain horse velocities which provides useful estimates for multiple needs: assessing if there are issues in a horses gait, cadence and stride in training and racing environments; provide real-time analysis for in-play betting; and provide pre-race analysis of runners for race prediction. The first method uses gate-based technology with physical/GPS technology, the second a video-based transformation method using CV and AI.

We provide the framework for the system and demonstrate its utility in a few environments – training, race and post-race. We cover challenges and outcomes from the process and compare the velocities recording using speed gates to the CV models garnered from vision. We also outline the process of extracting baseline velocities and how this approach can also be utilised for in-play Bayesian estimations of performance for setting prices and estimating outcomes.

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Tennis match outcome prediction using temporal directed graph neural networks

by ***Lawrence Clegg***, John Cartlidge **CS** SA083

We present the first application of a graph neural network for tennis match outcome prediction. Using MagNet, an existing spectral graph neural network for directed graphs, we construct temporal directed graphs by representing players as nodes and surface-specific historical match outcomes as edges. The model is trained and evaluated using a dataset of Grand Slam, ATP Masters 1000, and WTA 1000 events from 2007 to the conclusion of the US Open in September 2024. Following hyperparameter optimisation, a tuned model on the out-of-sample data achieves comparable predictive accuracy to the benchmark surface-adjusted Elo rating system (i.e., 62% compared to 65%) and outperforms the Bradley-Terry model (61%). Many recent advancements in tennis match prediction have focused on incremental improvements to the Elo rating system, such as incorporating margin of victory and surface-specific adjustments. Our research shifts this paradigm by demonstrating that graph neural networks, which inherently capture complex relational and temporal dynamics, offer a powerful alternative for pairwise comparison tasks such as tennis match prediction.

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Detecting match-fixing in professional football: The potential of in-game betting data

by ***David Winkelmann***, Christian Deutscher **CS** SA084

Match-fixing significantly affects public interest in sports and has substantial economic consequences. While previous literature has already addressed the issue of detecting corruption based on pre-match data, our study focuses on developing an automated alert system to identify suspicious football matches through the inclusion of in-game betting behaviour and volumes placed. For this purpose, we utilise a unique dataset from the 2018/19 seasons of the German Bundesliga and Italian Serie B, covering in-game betting odds and stakes recorded at a high frequency of 1 Hz. While match-fixing has been previously confirmed in the Serie B, the German Bundesliga serves as a benchmark due to its lack of known incidents. By applying time series analysis, we propose a data-driven approach that has the potential to exacerbate fraudulent activities by agents in the betting market, thereby enhancing sports integrity and consumer confidence in betting markets.

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Prediction-based evaluation of back-four defense with spatial control in soccer

by ***Soujanya Dash***, Kenjiro Ide, Rikuhei Umemoto, Kai Amino, Keisuke Fujii **CS** SA085

Defensive strategies in soccer are crucial to preventing goal-scoring opportunities and maintaining team structure. The defensive line (e.g., back four or back three) plays a vital role in these strategies. Despite its importance, evaluating the contribution of defensive line configurations remains an area of active research. This study hypothesizes that collective actions of the defensive line significantly contribute to a team's defensive success by maintaining defensive compactness. To test this hypothesis, we propose novel defensive indicators based on the predictive evaluation approach, including rule-based spatial control, defensive compactness, and pressure indices, handcrafted using the event and tracking data. Rule-based spatial control penalizes defenders when attackers are near the penalty box and rewards the defenders positioned closest to the on-ball player. Statistical analysis reveals that rule-based spatial control served as a significant indicator for distinguishing defensive success and failure ($p < 0.05$), whereas defensive compactness did not have a significant impact in determining defensive success or failure ($p > 0.05$). These findings challenge conventional assumptions about compactness and emphasize the importance of spatial control.

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Sports Analytics 9

Does fatherhood impact the performance of professional cyclists?

by ***Jeroen Belien***, Anke Baetens, Filip Van den Bossche **CS** SA091

This study examines the impact of becoming father on the performance of professional road cyclists. Fixed effects panel regression is used to compare cycling performance over a period after having a child with the performance in the same period the year before. The sample includes 299 professional male road cyclists who had one or more children between 2001 and 2019, with a total of 496 children. After correcting for personal and team related factors, cycling performance is significantly lower after the birth of a child. This is a first indication that having a child can influence the performance of professional athletes in a negative way. The results of this study may help to provide better psychological and athletic support for recent fathers, and are potentially relevant to contexts other than professional (cycling) sport.

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Evaluating Soccer Player Movements Using the Attacker-Defender Model

by ***Takuma Narizuka***, Issei Yamazaki **CS** SA092

In football (soccer) analytics, motion models are widely used for various applications, including the calculation of dominant regions, player trajectory generation, and pass outcome prediction. We focus on the Attacker-Defender (AD) model proposed by Brink et al., published in Scientific Reports 13, 19004 (2023), a physics-based model grounded in equations of motion. The AD model describes the interaction between a ball carrier (attacker) and the nearest defender during the ball-possession phase in a soccer match. The model is formulated as a system of ordinary differential equations for both the attacker and the defender. Each equation comprises three components: resistance, a player's driving force toward the goal, and a force directed toward the opponent. The trajectories of the attacker and the defender obtained from the AD model depend on the initial conditions and the six parameters of the model. By tuning these parameters, the model can accurately reproduce a variety of actual player trajectories observed during dribbling situations. One advantage of the AD model is its high interpretability, as the parameters have clear physical meanings. However, previous studies have primarily focused on a limited range of parameter values, and the model's applicability to real-world tracking data has not been fully explored. This study has two main objectives. First, we improve the parameter optimization process for the AD model. In particular, we propose a method to solve the AD model for one player by treating the opponent's actual trajectory as given and refine the error function to generate more realistic trajectories. Second, we quantitatively extract characteristic players based on the parameters of the AD model. By expanding the range of analyzed parameters, we provide new insights into the playing styles of attackers and defenders. We analyzed a comprehensive dataset of J-League matches, comprising tracking and event data from 306 matches provided by DataStadium Inc. Our findings contribute to a more detailed evaluation of player movements and can be applied to tactical analysis, player scouting, and training strategies.

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The Impact of Geoclimate Factors on Performance of Football Teams

by ***Iuliia Alekseenko***, Dmitry Dagaev, Daria Tabashnikova, Gleb Vasilyev **CS** SA093

Predicting the sports competition outcomes is one of the most well-known tasks in sports economics. Predictive models have become widely used in this field. Modern models for predicting sports events, particularly football games, include both classical statistical approaches based on extended Poisson models (Maher, 1982; Dixon, 1997) and contemporary machine learning methods (Berrar, 2019; Berrar, 2019b; Hubacek, 2022; Bunker, 2022).

The most accurate predictive models in football incorporate a wide range of variables, including offensive and defensive characteristics, team composition, opponent strength and home advantage (Berrar, 2019b). In practice, bookmaker odds—an aggregate estimate of event outcome probabilities—are frequently included in models as strong predictors or are used separately to evaluate their quality (Berrar, 2019b; Forrest, 2005; Hvattum, 2010).

Meanwhile, professionals continue to discuss how the density of the playing schedule may influence the performance. For instance, Josep Guardiola, head coach of Manchester City FC, has attributed a series of setbacks to an overloaded schedule leading to injuries among key players. Moreover, it is widely acknowledged that environmental factors—such as high temperatures during competitions—can affect athletes' performance (Saunders, 2019), as well as other external factors associated with traveling between venues. Specifically, travel distance and time zone changes can significantly impact sleep and circadian rhythms, thereby influencing athletic performance (Leatherwood, 2013).

Using data from 7,000 Russian professional football matches played between 2012 and 2024, we test hypotheses regarding the influence of several geoclimatic variables—temperature, travel distance, and time zone differences—on team performance, match outcomes, and a comprehensive analytical indicator: the expected goals metric. The uniqueness of Russian football lies in its geography: teams in the two top leagues, from Baltika in Kaliningrad to SKA in Khabarovsk, compete across a vast territory spanning 11 time zones.

We found that bookmaker odds explain a significant portion of the variance. This study demonstrates that away teams perform worse when crossing time zones based on the analysis of fixed-effects models comparing away teams' performances in matches played within their own time zone to those involving time zone shifts. The effects of time zones and travel distances on match performance are consistent with the results of classic studies (Leatherwood, 2013; Geurkink, 2021; Bai, 2022; Roy, 2017). Additionally, our model showed no significant effect of temperature differences between the home region and the match venue on team's performance.

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Sports Scheduling 4

A Column Generation Approach for First-Break-Then-Schedule

by ***David Van Bulck***, Jasper van Doornmalen, Dries Goossens **CS** SS041

In 1998, George Nemhauser and Michael Trick introduced the "First-Break-Then-Schedule" (FBTS) method for scheduling the ACC college basketball tournament. This three-phase approach first generates home-away patterns (HAPs) that define a team's home-away status for each round, then assigns each team to a HAP, and finally pairs teams with suitable opponents. While FBTS has gained widespread recognition in the literature for its effectiveness, it faces two critical challenges: the exponential growth of possible HAPs as the number of teams increases, making full enumeration impractical, and the lack of a systematic backtracking mechanism when pattern assignment proves infeasible. As a result, FBTS is more often used as a heuristic framework than as an exact decomposition method. In 1999, Martin Henz "revisited" the ACC scheduling problem using constraint programming rather than a mix of integer programming and exhaustive enumeration as originally proposed by Nemhauser and Trick. This paper presents another 'revisit' to the original ACC scheduling problem, addressing the limitations of FBTS by introducing column generation techniques in the break phase and applying Benders' decomposition in the schedule phase.

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Fair Schedules for Dreierturnier Competitions

*by **Sten Wessel***, Cor Hurkens, Frits Spieksma **CS** SS042

The Tata Steel Chess tournament is a chess contest where the fourteen best players in the world (measured by their so-called Elo rating) are invited to play a single round robin tournament. In the 2002 edition of this tournament (then called the Corus Chess Tournament), the #2 player of the world, called Michael Adams, faced the strongest 7 other players while playing black, and the remaining 6 weakest players while playing white. This imbalance had the potential to distort the outcome of this tournament, and is an extreme example of a more frequently occurring situation where the schedule may favor some players over others. We show how to remedy this, and arrive at fair schedules for single round robin tournaments (SRR) where a ranking of the players is prespecified.

We introduce a new measure to capture the fairness of an SRR tournament when participants are ranked by strength. With only one match between any pair of opponents, one participant will have the asymmetric advantage of playing at home (or in the case of chess, playing with white), having a positive effect on the match outcome for that participant. To prevent distortion of the outcome of an SRR tournament as well as to guarantee equal treatment of the participants, we argue that each participant should face its opponents when ranked by strength in an alternating fashion with respect to the home/away advantage. Here, the home/away advantage captures a variety of situations.

We provide an explicit construction proving that so-called single-break, ranking-fair schedules exist when the number of participants is a multiple of 4. Further, we give an integer programming formulation that outputs single-break ranking-fair schedules when they exist. We computationally show that such schedules exist when the number of participants exceeds 14, up to 98 participants. Finally, we show that the circle method, the most popular method to come to a schedule for an SRR tournament based on the Canonical Pattern Set, does not allow ranking-fair schedules when the number of teams exceeds 8. These findings impact the type of schedules to be used for SRR tournaments.

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Notes

Exploring the 2024/2025 format of the UEFA Champions League

by ***Javier Marenco***, Matías Córdoba, Juan José Miranda Bront **CS** SS043

The UEFA Champions League (UCL) is one of the premier football leagues in the world, featuring the best teams from all European football federations. Up to the 2023/2024 edition ,the UCL was organized in two stages: a first group stage (with the teams partitioned into four-team groups and each group playing a double round-robin mini-tournament) and the knockout stage (featuring the best two teams from each group). Starting with the 2024/2025 edition, the first stage has been replaced by a so-called "league stage", in which 36 teams participate in a single league playing eight matches each, against eight different teams. A general ranking among the 36 teams is thus generated, and the first 24 teams advance to the knockout stage.

A crucial aspect of the scheduling of the league stage is the determination of the eight rivals for each team. This procedure is performed with a draw aiming to provide a fair set of rivals for each team. In this work we are interested in the implications of this procedure and, in particular, we aim to estimate how the final ranking of the incomplete round-robin league stage compares to the (unknown) ranking of a complete double round-robin hypothetical tournament. To this end, we take data from past European leagues, we simulate the UCL league stage, and we compare the final ranking of the league stage with (a) the final ranking of a hypothetical league stage with rivals generated by using the UEFA coefficient and (b) the final ranking of a post-hoc model trying to generate a set of rivals providing the ranking most similar to the complete double round-robin ranking. Although these experiments cannot be directly extrapolated to the UCL competition, we believe that this line of research is promising in order to explore the pros and cons of the proposed format for the UCL.

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E-sports 1

The Effect of Home Advantage in eSports

by ***Mikhail Usanin***, Iuliia Naidenova, Petr Parshakov **CS** ESO11

The relevance of this study is driven by the rapid growth of eSports and the need to explore factors influencing competitive outcomes. While the phenomenon of home advantage has been extensively studied in traditional sports, its impact on eSports has not been previously examined. This paper investigates the effect of home advantage in professional Counter-Strike matches using data from 2012 to 2022. The analysis is conducted at both the individual level (player performance) and the team level (round difference in matches). Binary variables were constructed to assess home advantage, reflecting whether the tournament location coincided with the residence of a player or the majority of the team members. A panel data regression analysis revealed that competing in one's home country significantly improves individual performance, while having at least one player with home advantage enhances team results. This effect intensifies in the final stages of tournaments but diminishes in events with large prize pools, likely due to increased competition. Additionally, greater distance between a player's residence and the competition venue negatively affects individual performance. This study is the first to explore the impact of home advantage in eSports, contributing to a deeper understanding of competitive factors in this emerging field and paving the way for further research into determinants of success in professional gaming.

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Choking Under Pressure in Online Chess: Performance Decline Among Elite Players in High-Stakes Matches

by ***Elijah Sumernikov***, Dmitry Dagaev, Petr Parshakov, Gleb Vasiliev **CS** ESO12

The phenomenon of choking under pressure in sports has been extensively studied, with performance deterioration observed across numerous traditional and esports disciplines. However, previous research indicates that the most skilled athletes do not consistently exhibit this effect, and that experienced players tend to overcome or significantly reduce choking under pressure over time as they adapt.

Overall, the phenomenon of choking under pressure has received limited scholarly attention within the context of online sports disciplines, particularly in the domains of esports and online poker. In this study, we examine a discipline that, to the best of our knowledge, has not previously been analyzed in this context—online chess. Specifically, we analyze data from the recurring online tournament Titled Tuesday on the chess.com platform, which regularly attracts the most accomplished chess players. Our dataset comprises performance records from 466,000 games across more than 250 weekly tournaments since early 2022.

Our findings reveal that the choking under pressure effect is present among the group of contenders for tournament victory, including the highest-rated and most successful players. Notably, as the tournament approaches its final stages, players trailing the leader by no more than half a point exhibit a pronounced decline in performance, with the most significant drop occurring in the final (11th) round. In contrast, players who are not in contention for victory tend to demonstrate improved performance. Our analysis reveals that even highly experienced players are not immune to choking under pressure.

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Notes

Strategic Choice in eSports: An Analysis of Team Decisions During Map Vetoes

*by **Egor Ivanov***, Evgeniya Shenkman, Petr Parshakov, Mariia Molodchik **CS** ESO13

The study of strategic choice, a cornerstone of economic theory, provides insights into how individuals and organizations optimize outcomes. In eSports, particularly in Counter-Strike: Global Offensive (CS:GO), understanding teams' strategic choices during map selection and vetoes offers a way to analyze broader economic theories on decision-making.

ESports provides an ideal setting for testing strategic choice theories due to its structured, data-rich environment. CS:GO tournaments, in particular, generate large datasets of strategic decisions, enabling empirical validation of theoretical models. This study develops a theoretical model to explore how teams make map selection and veto decisions in CS:GO. Each map has unique characteristics that can benefit or disadvantage teams. Our model examines whether teams prioritize playing on their strongest maps or focus on limiting their opponents' advantages. The study also investigates how these decisions evolve based on the relative strengths of competing teams.

To validate our theoretical model, we analyze real-world data from professional CS:GO tournaments. The dataset, sourced from hltv.org, includes 5,600 matches from 2015 to 2024, covering strategic veto decisions, match outcomes, match types, and teams' map win rates in the three months before each match.

Our empirical findings suggest that as the veto process progresses, the impact of a team's own map win rate on veto decisions diminishes. Initially, teams eliminate maps where they have weaker performances. However, as the process advances, they increasingly prioritize removing maps where their opponents have high win rates. This shift indicates that teams move from optimizing their own selections to counteracting their opponents' strengths. In early veto stages, teams focus on their own historical performance, while in later stages, they remove maps that could significantly benefit their opponents.

Our results indicate that map veto decisions are shaped by prior experiences, map preferences, and strategic assessments of opponents. These findings contribute to the broader literature on strategic decision-making in eSports and economics, offering insights into competitive strategy and economic theory applications in digital environments.

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Sports Analytics 10

Evaluating player influence and team synergy in Soccer

by ***Ebrahim Patel***, Peter Grindrod, Andrew irving **CS** SA101

In Association Football, attacking players are conventionally ranked according to how many goals they score or create. The disadvantage of this ranking system is clear: it does not account for the strength of opponent. Here, we establish the concept of a 'par' for each opponent: the average number of attacking contributions against that team. By dividing Opta player data by the opposing team's par, we obtain more equitable statistics.

These standardised data provide models of player influence in the 2011/12 and 2023/24 English Premier League seasons. Moreover, we can model the influence of 2 players as a duo by using products of their individual standardised scores. We call the average of all such products the 'duo score' of that pair of players. The resulting scores represent the combined strength of each attacking duo, allowing coaching staff to identify the strongest and weakest attacker combinations.

Interestingly, a team's average duo score appears to be a good predictor of that team's rank in the final Premier League standings. In fact, just one club recorded a top-half mean duo score, but a bottom-half final standing in the 2011/12 season. Aston Villa finished 16th in the league, despite their squad achieving the 4th highest average duo score. Villa's average duo score was peculiarly elevated by their squad's highest duo score. This suggests Villa were unusually reliant on their most influential player. We propose that the forced retirement of team captain, Stiliyan Petrov, with 9 games remaining might explain these results.

Our duo scores represent how well players p and q play together, but not how responsible each player is for their shared successes. We define the 'influence' of p on q to be the ratio of p's average duo score with q to their average duo score without q. It proves instructive to view players as nodes in a team network, and this influence as the weight of an edge from p to q. In a team network of this kind, we can more easily identify the circuits of greatest weight - representing the strongest attacking duos, triumvirates and larger groups - with algorithms grounded in Max-Plus Algebra.

Team structures are crucial to organisational success. As our tools for the identification of key employees and groups are easily transferable to other sporting (and even non-sporting) organisations, we expect this work to be beneficial to management on a wider scale.

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Brains or legs: How to organize a fair rogaining competition?

*by **Dries Goossens***, David Van Bulck, Benjamin Jacquet, Joonas Pääkkönen **CS** SA102

Rogaining is an orienteering running sport where participants need to decide what control points to visit and in which order. The objective is to collect the largest possible score associated with the visited controls, without violating the time limit. While extensive literature exists on the orienteering problem from a participants' point of view, there is limited understanding of how to design a rogaining contest where physical abilities do not dominate over cognitive skills in influencing the race outcome. To create these contests, we propose a heuristic bilevel optimization approach where at the upper level organizers assign scores to candidate control points, while at the lower level participants solve the classic orienteering problem. The simulation of the selected courses by the participants results in a provisional ranking which allows to evaluate the score assignment as determined by the organizer at the upper level. We apply our methodology to the 2023 World Rogaining Championships, demonstrating the necessity of thoughtful score allocation to ensure a balanced emphasis on both skills.

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A Survival Analysis of Dropout among French Swimmers

by ***Audrey Difernand***, Alexia Mallet, Quentin De Larochelambert, Robin Pla, Andy Marc, Kilian Barlier, Juliana Antero, Jean-François Toussaint, Adrien Sedeaud **CS** SA103

This study examines the dropout rates among French swimmers based on performance levels, sex, and relative age. Using data from 160,861 swimmers under the age of 21, we analyzed the distribution of birth quarters and dropout rates across performance levels. Chi-squared tests were conducted to confirm the significant effect of birth quarter on performance. Kaplan-Meier Survival (KMS) curves were used to evaluate and interpret the impact of sex and relative age on dropout trends. The results show that dropout peaks occur at 13.16 years for girls and 17.50 years for boys. Analyzing by age year, at 13 years, the top 10% of female swimmers exhibit a dropout rate of 8.7% (9.9% for males), while the bottom 10% show a much higher rate of 78.1% (69.3% for males). By 17 years, the dropout rate rises to 39.6% (28.6% for males) for the top 10% and 91.7% (83.4% for males) for the bottom 10%. KMS curves, stratified by age, reveal similar dropout trends for both sexes below the age of 13. However, after this age, the dropout rate increases more sharply among females, reaching a maximum difference of 4.8% at 17.9 years. Disparities in dropout rates based on birth quarters are most pronounced at 12.7 years for girls (10%) and at 14.7 years for boys (8.1%). This study underscores the significant influence of sex, relative age, and performance level on dropout rates among French swimmers. Higher performance levels are associated with lower dropout rates, and female swimmers display consistently higher dropout rates than their male counterparts.

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Kinematic Variables and Match Outcomes in Serie A: Evaluating Their Impact With and Without Ball Possession

by ***Antonio Lucadamo***, Cristian Savoia, Francesco Laterza, Dario Pompa, Paolo Troiani, Maurizio Bertollo

CS SA104

This study aims to explore how kinematic, mechanical, and metabolic parameters influence match outcomes in the Italian Serie A during the 2022/2023 and 2023/2024 seasons. While existing literature has highlighted the impact of physical demands on team performance, limited attention has been given to the Italian league, especially concerning the role of ball possession phases. Our objective is to fill this gap by analyzing key performance indicators (KPIs) derived from tracking data, focusing on how these metrics relate to different match results (win, draw, loss). Key variables analyzed were Total Distance Covered (TDC), High-intensity acceleration distance (>3 m/s^2); and Metabolic Power High-Intensity (D_MPHI). Our findings reveal the importance of high-intensity actions, particularly accelerations, in influencing match outcomes. This insight aligns with existing literature emphasizing the tactical value of aggressive pressing and rapid transitions. Coaches and performance analysts can leverage these findings to prioritize training interventions that enhance players' explosive capabilities, potentially leading to improved competitive performance. By integrating advanced statistical modeling with applied performance analysis, this study contributes to a deeper understanding of the physical demands in elite soccer and their relationship to tactical success in Serie A.

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Gender differences and peer effects: The case of marathons

by ***Daria Tabashnikova***, Anna Gushchina, Sofia Pirogova, Igor Tylkin **CS** SA105

People's productivity is affected by their environment, including interactions with others, known as the peer effect. This impact varies depending on context and can be positive (Duflo et al., 2011; Ammermueller & Pischke, 2009) or negative (Battiston et al., 2021). Women and men react differently to these influences, with studies showing women tend to become more competitive when more friends enter a contest (Jørgensen et al., 2022). Peer effects have been studied in sports like swimming and running, where both positive (Yamane & Hayashi, 2015; Hill, 2014) and negative impacts (Emerson & Hill, 2018) have been observed. Our study focuses on how the competitiveness of a race affects individual performance. Unlike prior work using the presence of a superstar or opponent quality as proxies for competitiveness, we introduce a novel measure based on the number of participants with similar career-best times. Analyzing Russian marathon data from 2016-2022, our regression model included factors such as age, gender, weather conditions, and type of event. Results indicate that increased competitiveness benefits women's performance up to a point, after which additional competitors start reducing performance. No significant effect was found for men. This gender disparity may stem from differing attitudes toward risk, with women becoming more risk-prone in competitive environments (Harris & Jenkins, 2006; Jetter & Walker, 2017). Logit models revealed that male professionals were more likely to drop out of marathons, suggesting greater risk-taking among men. Additionally, the number of participants had an inverse U-shaped relationship with the probability of non-completion, particularly affecting women.

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Sports Analytics 11

Detection of front-door and back-door pitches in baseball and the characteristics that make them effective

by ***Takumi Miura***, Keisuke Fujii **CS** SA111

Front-door and back-door pitches (hereinafter referred to as “door-type pitches”) refer to laterally breaking balls that move from outside to inside the strike zone. Door-type pitches often induce called strike or weak contact, but they carry the risk of hard hits. However, there are no clear criteria for detecting door-type pitches and their effectiveness has not been verified. This study aims to clarify the requirements for whether door-type pitches are effective in NPB. First, we used data from MLB to construct a machine-learning model that estimates the amount of pitch movement, allowing us to detect door-type pitches in NPB. Next, we tested the effectiveness of door-type pitches and analyzed the relationship between the pitchers’ and pitches’ characteristics and the test results. The results suggest that some door-type pitches may be effective for pitches inducing weak contact, some front-door pitches may be ineffective for slow pitches, and some door-type pitches may be ineffective for pitches that break in the same direction as the pitcher’s throwing arm. These findings can help players and coaches refine and evaluate decision-making of their pitching strategies.

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Notes

A System for Tracking Players and the Ball in Association Football Matches using Regular TV Footage in conjunction with "Deep Learning" and Transformational Geometry

by ***Gordon Hunter***, Nikhil MUNESHWAR, Xing LIANG **CS** SA112

Sophisticated software for analysis of player performance and team tactics during sports matches is now commonplace on TV Sports coverage, for "pundits" to give in-depth analysis to fans during breaks in, or at the end of, the game. Such software is also used by coaches and managers of top clubs to work out what went right and what went wrong in the match, and they can also analyse footage from other teams' matches to help develop strategies and tactics for use when their team plays one of those others. However, such software often relies on footage from multiple camera views, using very high frame rate cameras. Hawk-Eye* is one such system, and has been used with great success in TV coverage of sports such as cricket and tennis for over 20 years, but relies on triangulation from multiple camera views from expensive cameras and a lot of high performance computing.

In this paper, we describe our development and evaluation of a system for tracking players, match officials and the ball in "regular" frame rate TV footage of Association Football (Soccer) matches. The system distinguishes between players of the different teams, the match officials, and the ball, and is able to track all of these with very good reliability. Our system is based on the latest version of the "You Only Look Once" (YOLOv11) object detection algorithm, developed from the GoogleNet Convolutional Neural Network Architecture. The system is fine-tuned and trained on a dedicated dataset tailored to optimize detection performance in football-specific scenarios. Moreover, through implementing various transformational geometry and Newtonian dynamics calculations, we are also able to compensate for motion of the camera, and produce data and statistics for each player, such as their current speed of movement, and the total distance they have travelled during the game.

Although our system may not be a sophisticated as the "state of the art" ones used by major sports TV broadcasting companies, it has performed well when tested out on "regular" TV footage of professional Association Football matches. This could make it feasible for use by lower level and semi-professional clubs, or even fans' channels, relying on less advanced technology.

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De-compactification of Soccer Formations

*by **Hugo Fabrègues***, Ulrik Brandes **CS** SA114

In association football (soccer), average locations are customarily used to depict player positioning in static summaries of their movements over a period of time. This is common in representations of passing networks, or when media compare tactical formations with actual positioning. Since average locations tend toward the center, they create a potentially misleading impression of compactness that is not easily resolved by scaling, because it may stem from, for instance, collective shifting or pairwise switching.

Since the underlying positioning strategies are unknown to observers, and confounds the impact of everyone else and the ball on each player's movements, identification of an intended spatial organization is, in mathematical terms, an inverse problem.

We propose a model of collective movement in which players' locations are influenced by an (unknown and relative) reference position and the locations of other players. Influence relations are determined from event or tracking data, and lead to a Laplacian system of linear equations relating actual and hypothesized locations of all players. Since average locations are observed, this allows us to infer unique reference locations.

The result is a non-uniform de-compactification of average locations to potentially underlying reference locations. Parallels can also be drawn with differential equations systems modeling players' movements by forces acting on players. Thus, our approach can also inform simulations.

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Notes

What Drives Success in Men's Ice Hockey World (Junior) Championships?

by ***Vladimír Holý*** **CS** SA115

This study investigates the key factors influencing the success of national teams in the Men's Ice Hockey World Championships and the Men's Ice Hockey World Junior Championships. Specifically, we analyze the potential home advantage of hosting the tournament, the impact of past performances, and the role of players' physical attributes, including height, weight, and age. Additionally, we assess the value of experience gained from the World Championships compared to the NHL and other leagues. To model team performance over time, we employ a dynamic ranking model based on the Plackett–Luce distribution, incorporating time-varying strength parameters driven by the conditional score. Furthermore, we conduct a forecasting analysis to estimate the probabilities of winning the tournament, securing a medal, and advancing to the playoff stage.

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Data-Driven Performance Profiling of Club-Level Football Players in Mumbai

by ***Praveen D Chougale***, Usha Ananthakumar **CS** SA116

This study applies K-Means and Hierarchical Clustering (Ward's Method) to analyze the physical performance of male football players competing at the club level in Mumbai. Using data from drop jump testing, key performance variables-including jump height, flight time, peak power, active stiffness, concentric impulse, eccentric duration, and reactive strength index (RSI)-were assessed to cluster athletes based on their physical attributes. The optimal number of clusters was determined using the Silhouette score, leading to the identification of two distinct performance profiles. R^2 values and RSQ ratios highlighted concentric impulse, peak power, and jump height as the most significant differentiating factors between clusters. The Developing Athletes profile consists of younger players with lower peak power, jump height, and concentric impulse, along with reduced flight time and eccentric duration, suggesting a need for targeted strength and power training. In contrast, the Elite Athletes profile comprises older, more physically developed players with significantly higher peak power, jump height, and flight time, reflecting superior explosiveness and force production. These findings provide a data-driven framework for talent identification, training optimization, and performance benchmarking, supporting structured development pathways for competitive footballers.

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Sports Analytics 12

Predicting International Success Based on Domestic Performance in T20 Cricket

by ***Ali Iltaf***, Richard Allmendinger **CS** SA121

This study aims to find the driving factors for successful performance for England's players in international T20 cricket based on domestic performance and predict the performance of players who haven't played internationally. The results in this study can be used to inform the player selection process for the England team and discover new talent that may not have been recognised by selection staff and coaches. This research was done in collaboration with the England and Wales Cricket Board (ECB).

The data used for this study was provided by the ECB. This data includes ball-by-ball data on every T20 officially recorded, including both international and domestic matches, from the start of 2010 up until 23rd October 2024. The data includes key details from the match the delivery was played in and more detailed data on each delivery, such as the information that can be found about the scorecard, shot and delivery types, foot movement for the batsman, as well as some ball-tracking data.

Batters, pace bowlers and spin bowlers are all considered separately. The same process of feature selection and model training is applied to each group. Although pace bowlers and spin bowlers use the same initial set of features, they are analysed separately since the driving factors for successful performance are likely to be different due to the vast difference in bowling style.

The ball-by-ball data is aggregated to calculate metrics for individual players. These metrics include traditional metrics such as the strike rate as well as metrics which make use of the ball-tracking data. The use of ball-by-ball data allows for the calculation of context-aware metrics such as the Net Contribution, a Duckworth-Lewis resource-based player performance metric. A modified version of the Duckworth-Lewis resource formula was introduced to fit the characteristics of a T20 game. The Net Contribution using the modified resource calculation is used to evaluate player performance for both bowlers and batsmen in this study.

Features are selected using two methods. The first method uses minimum redundancy maximum relevance (mRMR) with mutual information as the measure of relevance and redundancy for optimal feature selection. Both the difference method and the quotient method for mRMR are used to produce features. The second method clusters features using Spearman's rank correlation coefficients, then one features is used to represent each cluster and the features are selected using permutation importance scores for each cluster. Each method is used separately, and models are trained and tested using both sets of features. Linear Regression, SVRs, Decision Tree Regression, Random Forest Regression and XGBoost Regression are all used for the regression models to predict player performance at the international level.

SHAP scores are analysed for the best performing models from each player category to determine which features are driving factors for predicting performance, and to determine the effect of those factors on performance.

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Rethinking the evaluation of performance in football: A novel mathematical framework to quantify the quality of key performance indicators.

by ***Fabian Wunderlich***, Andreas Heuer **CS** SA122

When analyzing datasets, sports scientists often resort to methods of classical inferential statistics or increasingly to machine learning. Both approaches have weaknesses, as the former may not be fully suited to the problem at hand and the latter lack explainability, i.e. the ability to infer anything about the processes inherent in sport.

Mathematical modeling can help to find methods both suitable and explainable, which we show using the example of performance analysis. A variety of so-called key performance indicators (KPIs) are available to characterize the performance of teams in football matches. A large body of literature attempts to establish relationships between these performance indicators and success by finding KPIs significantly related to match results. However, current methods fail to theoretically define the concepts of interest, to avoid confounding factors of scoreline in the analysis, to directly compare the quality of KPIs and to statistically explain why some KPIs are superior to others.

Inspired by the so-called correction for attenuation, we derive a mathematical framework to define the four concepts predictability, consistency, reliability and quality and infer their specific values from data. We define predictability as the ability of a performance indicator to predict success, measured by the correlation between a performance indicator in one half of the season and the success (goal difference) in the second half of the season.

We show that predictability is dependent on (and the product of) three factors: 1) The consistency of a KPI, which we define as the correlation between the performance indicator and the success if randomness was absent for both components. We achieve this by conceptually assuming an infinitely long season, where a team theoretically plays an infinite number of matches against all other teams in the league. 2) The reliability of a KPI being driven by a low volatility of the KPI. 3) The reliability of goals being imperfect due to the inherent outcome uncertainty in football results.

Please note that even a perfect KPI can only optimise the first two components. Thus we factor out the last component and define the quality of a KPI as the predictability divided by the reliability of goals. We obtain the quality for all KPIs from the data and can explain it directly by breaking it down to the two remaining factors consistency and reliability (of the KPI).

We apply our framework to four of the biggest European men's football leagues in seasons 14/15 to 21/22 ($>$10,000 matches) for the following KPIs: Goals, points, corners, shots, shots on target, the so-called expected goals metric (xG) as well as a metric derived from betting odds. Goals are found to have a quality of 0.862 based on a perfect consistency of 1.00 (by definition) and a reliability of 0.862 . Metrics like shots on goal reach a slightly higher quality despite non-optimal consistency (0.865=0.972$\times$0.890) while the best KPI is xG (0.893=0.983$\times$0.909). We also note that betting odds, although conceptually different from the other metrics, can be included in the framework and have an almost perfect quality.

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Estimation of match abilities for tennis players via a maximum likelihood approach

by ***Hannah Bartmann***, Andreas Groll, Rouven Michels **CS** SA123

In this work, a weighted likelihood approach is used to predict match abilities in professional men's singles tennis. The data used include both ATP Tour events and Challenger matches. A weighted likelihood for a binary response variable is proposed, with the weights being composed of both a match importance and a time depreciation factor. Seven models with different weighting schemes are compared via three different performance measures, namely classification rate, predictive Bernoulli likelihood and Brier score. While we do not weight observations in the first model, the other models use a match importance factor and varying time depreciation factor, ending up with seven models in total. In order to compare these models, a rolling window approach is employed to predict the outcome of the matches of the tournaments between May 2023 and May 2024. The models estimate strength parameters for the players, which can be used in further enhanced statistical learning approaches as informative features.

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Notes

Performance Monitoring in Middle and Long Distance Running and its Application to the Athlete Biological Passport

by ***Laurentiu C. Hinoveanu***, Jim Griffin, James Hopker **CS** SA124

As the aim of any doping regime is to improve sporting performance, it has been suggested that analysis of athletes' competitive results might be informative in identifying those at greater risk of doping. The aim of this research project was to investigate the utility of a continuous-time Bayesian longitudinal statistical performance model to discriminate between athletes who have been flagged at risk of doping. Doping is not observed, and several proxies are available through the athlete biological passport (i.e. an adverse analytical [AAF] or adverse passport finding [APF]), or with a historical anti-doping rule violation (ADRV), and those presumed clean.

We analysed performances of male and female 800 – 10,000m runners over the years 2011 to 2023 obtained from the World Athletics results database. We allow for the effects of confounding variables including seasonality and the interaction between running distance and competition year, with career performance trajectories adjusted accordingly. Measures of unusual improvement in performance were quantified by comparing the yearly change in the athlete's performance (delta excess performance) to their age-matched peers from the database population to identify those who may be at greater risk from a performance perspective. We evaluate and compare the ability of this approach to discriminate between the performance of athletes under different doping proxies (AAF, APF or ADRV) using the area under the ROC curve, and estimating the True and False Positives.

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From Advantage to Action: How Managers Adapt to External Conditions Strategically

by ***Andrei Smirnov*** **CS** SA126

Managers in competitive environments face high-stakes decisions with direct consequences for outcomes. In team sports, strategic pre-match choices—such as determining the starting lineup—highlight how managers optimize performance by utilizing factors like home advantage (i.e., the well-documented phenomenon where teams perform better when playing in their home environment). Analyzing these decisions provides insight into whether managers adjust strategies in response to external conditions and whether these adaptations align with theoretical models. This study explores how home advantage influences football coaches' tactical approaches, particularly their propensity to adopt more offensive strategies when playing at home. We propose a novel proxy to identify attacking lineups, focusing on player performance indicators, such as recent goal-scoring achievements (short-term) and cumulative season goals (long-term). By investigating how these metrics affect lineup choices, we gain a clearer understanding of how coaches integrate offensive form into their decision-making process. Our approach not only sheds light on the behavior of managers in football but also enriches broader discussions on strategic adaptation across varying contexts. Given the complex interplay of risks and rewards in these decisions, it is useful to frame them within established theoretical models. Game theory, with its emphasis on strategic behavior, offers valuable insights into how managers might adjust their strategies under different conditions, such as the presence of home advantage. One key concept in game theory is the minimax strategy, which informs optimal decision-making in zero-sum scenarios. Yet, in dynamic, real-world contexts like team sports, whether managerial decisions consistently reflect such theoretical predictions remains uncertain. A particularly fascinating domain for applying these concepts is the world of sports, where strategic interactions are central to both individual and team performance. Within this context, one factor stands out as particularly influential—home advantage. The concept of home advantage, widely documented in sports, refers to the tendency for teams to perform better when playing in their home stadium compared to away games (Carmichael & Thomas, 2005). This phenomenon has been attributed to a range of factors, from crowd influence to familiarity with the playing environment, and even psychological factors linked to defending one's "territory" (Agnew & Carron, 1994; Clarke & Norman, 1995; Neave & Wolfson, 2003). Despite extensive research on home advantage, most studies have focused on in-game performance metrics—such as scoring patterns, referee decisions, and overall player behavior—rather than pre-game coaching strategies. Consequently, it remains an open question whether coaches actively adjust their strategic choices before the match, based on the expectation of home advantage. Understanding this dynamic could offer new insights into how strategic decision-making processes adapt to external conditions. We provide robust evidence that coaches, as experienced decision-makers, adapt their strategies to align more closely with Nash equilibrium predictions. They achieve this by adopting more offensive lineups and favoring players with strong Long and Short Run recent offensive performances, particularly forwards and midfielders. These findings underscore the rational and systematic nature of managerial adjustments under external conditions, which are often supported by coaching staff and analytics teams.

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Sports Analytics 13

Evaluation of the new Champions League format

by ***Karel Devriesere***, Dries Goossens **CS** SA132

Recently, UEFA changed the group stage of its international club competitions to an incomplete round robin tournament. In the old format, teams were partitioned into groups and each group was organized as an independent round robin tournament over 6 matchdays. Moreover, each group had its own separate ranking, and qualification for the knockout stage was determined only by the ranking of teams within their group. In contrast, the new format has all teams competing in one single league, producing a single ranking table. Instead of seeing 3 opponents twice, teams now face 8 different opponents once, and qualify for the knockout stage based on their final rank relative to all other teams. The goal of switching to this new format for UEFA was to have "more competitive matches for every club across the board". In this study, we are interested in whether the claim of UEFA is justified. We do this by investigating the effect of the new format on the expected number of noncompetitive matches in the UEFA Champions League. We define a match to be noncompetitive if the prize of one or both opponents is fixed regardless of the match outcome, or if there exists an opportunity for collusion. Then, we compare all 12 schedules for the old group stage format with several reasonable schedules for the new iRR format. Next, show with Monte Carlo simulations that the new format is indeed expected to contain more competitive matches. Integer programming is used to determine whether teams have secured a prize or whether this remains uncertain, as well as for simulating the draw and constructing the schedules in the new format.

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Advancing Sports Performance Analysis with Pose Sequences and Time-Series Deep Learning

by ***Qi Gan***, Stephan Clémençon, Mounîm A.El-Yacoubi, Sao Mai Nguyen, Eric Fenaux, Khalid Oublal, Ons Jelassi

CS SA133

Human movement analysis, particularly in sports performance, has been extensively studied using bio-mechanical and statistical models. Traditionally, experts extract key movement variables to analyze athletic performance and provide guidance for improvement. While machine learning (ML) has been applied in feature-based sports analysis, the potential of artificial intelligence (AI)—especially deep learning—remains under-explored in this field. One of AI's most powerful capabilities is its ability to extract meaningful insights from long sequences and time-series data. This characteristic presents new opportunities for sports performance analysis by representing the athlete's body through keypoints and modeling movement as pose sequences. However, the extent to which statistical models can extract meaningful physical insights from pose sequences remains an open question. This study aims to bridge modern AI advancements, particularly deep neural networks (DNNs), with pose-sequence-based sports performance analysis. Specifically, we apply time-series DNN models alongside explainable AI (XAI) techniques to analyze long jump pose sequences and identify key spatial-temporal patterns that contribute to performance. Here, spatial refers to the movement of specific body joints, while temporal denotes their evolution over time. To achieve this, we constructed a dataset of 386 long jump sequences sourced from online videos of the World Championships, Olympic Games, and European Championships. Athlete poses were estimated using state-of-the-art computer vision (CV) models, with minor manual corrections. We trained a time-series DNN model to predict effective jump distance from these pose sequences. To interpret the model's predictions, we employed a specialized time-series XAI model, which uncovered specific spatial-temporal patterns linked to successful jumps. For comparison, we also extracted expert-defined bio-mechanical features from the pose sequences and applied SHAP (Shapley Additive Explanations) to identify the most influential features. By relating the patterns identified by time-series models to the key features derived from feature-based analysis, we provide a comparative evaluation of both approaches. Additionally, we contextualize our findings with existing research on long jump performance. This work highlights the potential of integrating deep learning with explainable AI for sports performance analysis. By combining pose-sequence-based modeling with expert-driven feature analysis, we provide new insights into long jump bio-mechanics, paving the way for more data-driven coaching strategies and performance optimization.

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Probing the gender divide in soccer: can technical and tactical features distinguish men's and women's soccer net of physiological differences?

by ***Gordana Marmulla***, Ivana Smokovic, Anh Nguyen, Hadi Sotudeh **CS** SA134

While interest, participation and investment in women's soccer continues to grow, effects of societal and financial barriers remain. At the same time, increasing availability of match data provides ever more opportunities to understand similarities and differences between men's and women's soccer. For example, existing literature based on a mixture of data sets and methods has found that men cover a higher total distance, have longer possession, a faster passing tempo, a higher volume of passes, and a higher passing accuracy. However, soccer is a physical game and the way in which it can be played is subject to the physiology of its players, with men and women differing notably in their physiologies. In contrast to previous approaches, we present a study in which investigates the gender gap in how soccer is played whilst explicitly controlling for the physical differences between men and women. Leveraging insights from existing literature and drawing on match data, we consider only those features which are not due to physiological differences but are inherently technical or tactical. Where necessary, this is done by modifying existing features in such a way as to strip out the physiological bias within them. The selected features are then used as the independent variables of a binary logistic regression to distinguish between men's and women's soccer.

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The trade-off between model flexibility and accuracy of Expected Threat models in football

by ***Koen W. van Arem***, Jakob Söhl, Mirjam Bruinsma, Geurt Jongbloed **CS** SA135

With an average football (soccer) match recording over 3,000 on-ball events, effective use of this data is essential for practitioners at football clubs to obtain meaningful insights. Models can extract more information from this data, and explainable methods can make them more accessible to practitioners. The Expected Threat model has been praised for its explainability and offers a low-threshold option for practitioners. However, challenging key design choices have to be made when applying the Expected Threat model. Using more variables and finer grids leads to a more flexible model that can better distinguish between different situations, but the accuracy of the estimates deteriorates with a more flexible model. The scientific literature offers little guidance on making these key design choices. Consequently, practitioners face challenges in balancing the trade-off between model flexibility and model accuracy. In this study, we analyse the Expected Threat model from a theoretical perspective and perform simulations based on the Markov chain of the model to examine its behaviour in practice. Our theoretical results establish an upper bound on the error of the Expected Threat model of different flexibilities. Our simulations provide insight into the actual error, and they show that the theoretical bound is overly conservative. Based on the simulated data, we provide a more accurate characterisation of the model's error, improving over the conservative theoretical bound. Finally, we convert these insights into a practical rule of thumb to help practitioners choose the right balance between the model flexibility and the desired accuracy of an Expected Threat model.

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Evaluating the Improved Linear Model (and its successor) with regards to the Expanded College Football Playoff

by ***John A. Trono***

CS SA136

Now that the College Football Playoff (CFP) has increased the number of invited teams from four to twelve, this article will compare how well the original model's weights performed in the first year of this expanded championship (2024). This article also includes the performance of a newly generated set of weights using the updated criterion of attempting to match this significantly larger group that the CFP committee now selects (as its dozen championship playoff participants).

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Mathematical and physical modelling of different forces in sports to get optimized performance in a Javelin throw

by ***Anand Kumar Yadav***, Gourav Gupta **CS** SA137

In sports, the application of forces is fundamental to understanding performance, optimizing techniques, and enhancing outcomes. Different forces such as gravity, friction, air resistance, and muscular force play key roles in athletic movements and can be optimized to improve performance across various sports. Specially in the javelin throw, gravity, air resistance, and muscular force interact to determine the distance and accuracy of the throw. Athletes must apply optimal force to launch the javelin at the correct angle of throw, while air resistance and gravity affect its trajectory and final distance. The horizontal Range (distance travelled by javelin) where is velocity of throw that dependent on muscular force, g is gravity force that is constant and is angle of throw. So, optimizing angle of throw to distance travelled by javelin will be maximum. Mathematical analysis helps determine the ideal launch angle and velocity to maximize the throw. Mathematical analysis, through the application of physics-based models, enables a deeper understanding of these forces and their effects. Advanced computational simulations help quantify these forces and predict optimal movement patterns. The ability to model these forces through mathematical tools and optimize predictions through data analysis leads to more effective training regimens, better performance optimization, and improved injury prevention. For instance, Gravity, friction, air resistance, centripetal force, and muscular force impact performance across various sports, from basketball to cycling, weightlifting, and swimming. Elastic and buoyant forces also play key roles in sports like archery, trampolining, and swimming, with the javelin throw highlighting the importance of gravity, muscular force, and launch angles in optimizing performance.

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Useful Information

History of Luxembourg

The origins of Luxembourg city

The origins and the name of Luxembourg are intimately linked with one person, and with one place.

City of Luxembourg: its Old Quarters and Fortifications
Photo credits: Limes.Media/Tim Schnarr

In the year 963, a Count by the name of Siegfried, a Carolingian by blood - and on his mother's side he was descended from Charlemagne, acquired from the St. Maximin Abbey in Trier a rocky promontory overhanging the valley of the River Alzette. According to the deed recording the transaction, a small stronghold called "Lucilinburhuc" was situated there at that time. It was probably of Roman origin. It was there that the name of Luxembourg first appeared in history. The name would pass to the city which took shape all about, and then be handed on to the country which developed around that city. Nowadays, the city and the country carry the same name.

According to legend, Count Siegfried would be married to Melusina, a mermaid who became a part of European folklore and who was to disappear beneath the waves of the Alzette. Be that legend or not, Siegfried was present at the very birth of the House of Luxembourg, a dynasty which, during the 14th century and the first half of the 15th century, was to provide four Emperors to the Empire and four Kings to Bohemia.

Source: `https://www.luxembourg-city.com/`

Scenes of a military past

Armies, military activities and war have all left their mark on Luxembourg. The extensive legacy and relics of these troubled times will still be visible in the cities and countryside for many years to come.

A walk through the capital already reveals numerous impressive examples: ramparts, the underground tunnels of the casemates and other fortifications planned and constructed by the famous French military architect and engineer Vauban are a reminder that the city was once a stronghold; so unassailable that it was known as the 'Gibraltar of the North'.

The World War II also left their traces in Luxembourg. Today, numerous memorials, monuments and museums remind visitors of how the country experienced these conflicts. You can also see the second world war through the eyes of Luxembourg's underground resistance movement – for example on the 'Sentier des

passeurs' (Smuggler's Trail), the 'Bunker Hike' circular walk in Schlindermanderscheid or at the National Resistance Museum in Esch-sur-Alzette.

Source: https://www.visitluxembourg.com/

A city of contrast

Hardly any other European capital city serves up such an impressive array of contrasts as Luxembourg. In the course of its history, spanning more than a thousand years, the city has grown from "Lucilinburhuc", the seat of Siegfried, the first Count of Luxembourg, to the prosperous metropolis it is today. In between lie centuries of turbulent history, reflected in the city's silhouette that towers above the impressive remains of the historic fortress.

The European Parliament in Luxembourg.
Photo credits: Luxembourg times

The city's topography is characterised by green river valleys that can be crossed by well over a hundred bridges, providing links between the historic and modern parts of the city. Its population is polyglot and cosmopolitan. Of the approximately 122.000, over 67% are foreigners, a fact that is reflected not least in the wide range of multilingual and international cultural events on offer.

We wish to welcome you with a very warm "bonjour", or "Moien" in luxembourgish!

University of Luxembourg

Founded in 2003, the University of Luxembourg is the only public university of the Grand Duchy of Luxembourg. Multilingual, international and research-oriented, it welcomes around 7,000 students and 300 professors from 135 nationalities.

The initial goal of the Belval campus was to create an "environment for research" without any plan for welcoming students. It took several years for the idea of transforming the old steel mills in Belval not just as a research centre, but as a university to take shape. The project encountered numerous difficulties for revitalising Belval partly driven by the ardous process of decontaminating the soil at the site. Initially the idea was that the university would draw inspiration from other new universities in the surrounding areas, specifically Leuven-la-Neuve with the aim of drawing in roughly 30,000 students.

When founded in 2003, the university was a combination of four separate education and research institutions: the Centre universitaire, Institut supérieur d'études et de recherches pédagogiques, Institut supérieur de technologie, and Institut d'études éducatives et sociales. The main academic life would remain spread over 3 spots: Campus Limpertsberg, Campus Kirchberg and Campus Walferdange.

In 2015, the university management and central administration moved to Belval which became the new headquarters of University as a symbol of the country's vision to invest in high-quality public research, a

major contribution to Luxembourg's economic future.

The values of the university are driven by excellence, agility, inclusiveness and fairness, independence and an international and multilingual environment grounded in the society.

Sources: `https://wwwen.uni.lu/university/about_the_university` / ROUX Student Magazine 1st issue, November 2022

How to connect to wifi?

The conference will be held at the Coque (on day 1 and day 2) and LUNEX (on day 2).

Eduroam will be available at LUNEX. You can use public wifi network at Coque. The city of Luxembourg offers free public wifi. You can simply connect to **citywifi**.

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