Ultimate Performance Analysis Tool (uPATO)
Implementation of Network Measures Based on Adjacency Matrices for Team Sports
SpringerBriefs present concise summaries of cutting-edge research and practical applications across a wide spectrum of fields. Featuring compact volumes of 50–125 pages, the series covers a range of content from professional to academic.

Typical publications can be:

- A timely report of state-of-the-art methods
- An introduction to or a manual for the application of mathematical or computer techniques
- A bridge between new research results, as published in journal articles
- A snapshot of a hot or emerging topic
- An in-depth case study
- A presentation of core concepts that students must understand in order to make independent contributions

SpringerBriefs are characterized by fast, global electronic dissemination, standard publishing contracts, standardized manuscript preparation and formatting guidelines, and expedited production schedules.

On the one hand, SpringerBriefs in Applied Sciences and Technology are devoted to the publication of fundamentals and applications within the different classical engineering disciplines as well as in interdisciplinary fields that recently emerged between these areas. On the other hand, as the boundary separating fundamental research and applied technology is more and more dissolving, this series is particularly open to trans-disciplinary topics between fundamental science and engineering.

Indexed by EI-Compendex, SCOPUS and Springerlink.

More information about this series at http://www.springer.com/series/8884
Ultimate Performance Analysis Tool (uPATO)

Implementation of Network Measures Based on Adjacency Matrices for Team Sports
Acknowledgements

The authors would like to thank Instituto de Telecomunicações—Covilhã, Instituto Politécnico de Coimbra—Escola Superior de Educação and Instituto Politécnico de Viana do Castelo—Escola Superior de Desporto e Lazer de Melgaço for the institutional support to make this book.

The authors would also like to thank: Bernardo Sequeiros for his scientific contributions in previous works and for his suggestions for this book; José Ribeiro and Vasco Lopes for the development of the web application presented in this book; Eduardo Cachulo, Francisco Campos, Ricardo Gomes, and Rui Mendes for their suggestions on new features, corrections, and testing of the application, during its development process.

Finally, the authors would like to thank their families for the permanent support and for their patience with their scientific activity. That is why this book is dedicated to them.

This work was conducted in the aim of the uPATO project from Instituto de Telecomunicações and funded by FCT/MEC through national funds and when applicable co-funded by FEDER—PT2020 partnership agreement under the project UID/EEA/50008/2013.
Contents

1 Network Analysis Tools ........................................ 1
   1.1 Introduction ........................................ 1
   1.2 A Brief Review on Software Tools ....................... 1
   References ............................................. 4

2 uPATO—Overview of the Application .......................... 5
   2.1 Network Manipulation Modules .......................... 5
      2.1.1 Creating Network ................................ 5
      2.1.2 Displaying Network ............................... 11
      2.1.3 Calculating the Metrics .......................... 12
      2.1.4 Presenting Results ............................... 14
   References ............................................. 17

3 uPATO—Individual Measures .................................. 19
   3.1 Centrality .......................................... 19
      3.1.1 Degree Centrality ............................... 19
      3.1.2 Closeness Centrality ............................ 20
      3.1.3 Stress Centrality ............................... 22
      3.1.4 Betweenness Centrality .......................... 23
      3.1.5 Eccentricity Centrality ......................... 24
      3.1.6 Eigenvector Centrality .......................... 24
      3.1.7 Subgraph Centrality ............................. 25
      3.1.8 Laplacian Centrality ............................ 26
      3.1.9 PageRank Centrality ............................. 26
      3.1.10 Power Centrality (Bonacich’s) .................. 27
      3.1.11 Centroid Centrality ............................ 28
   3.2 Prestige .......................................... 29
      3.2.1 Degree Prestige ................................. 30
      3.2.2 Proximity Prestige .............................. 31
3.3 Other .................................................................. 31
  3.3.1 Clustering Coefficient .................................. 32
References .................................................................. 34

4 uPATO—Collective Measures .................................. 37
  4.1 Subgroup Measures .......................................... 37
    4.1.1 Average Neighbor Degree ........................... 37
    4.1.2 Topological Overlap .................................. 37
  4.2 Team Measures .............................................. 40
    4.2.1 Total Links ........................................... 41
    4.2.2 Network Density ..................................... 41
    4.2.3 Average Distance .................................... 43
    4.2.4 Network Diameter .................................. 43
    4.2.5 Network Heterogeneity ............................ 44
    4.2.6 Transitivity ........................................... 46
    4.2.7 Reciprocity ........................................... 48
    4.2.8 Global Centralization ............................. 48
    4.2.9 Global Prestige ....................................... 49
    4.2.10 Assortativity Coefficient ......................... 50
References .................................................................. 60

5 uPATO—A Case Study ........................................ 61
  5.1 Case Study .................................................... 61
  5.2 Networks ........................................................ 61
  5.3 Individual Metrics .......................................... 62
  5.4 Subgroup Metrics .......................................... 69
  5.5 Team Metrics ................................................. 70
Reference .................................................................. 76
About the Editors

**Frutuoso G. M. Silva** is Assistant Professor of the Department of Computer Science at the Universidade da Beira Interior (UBI) and leader of the Regain group of Instituto de Telecomunicações (IT). He was one of the creators of the master degree in Game Design and Development of the UBI and was the coordinator of this master degree between February 2015 and November 2017. His current research interests include geometric modeling, augmented reality, and computer games. He is a member of the Eurographics.
For further details see: [http://www.di.ubi.pt/~fsilva/](http://www.di.ubi.pt/~fsilva/)
Contact: fsilva@di.ubi.pt

**Quoc Trong Nguyen** obtained his B.Sc. (2014) in Computer Science from Ho Chi Minh City University of Pedagogy, Vietnam, and M.Sc. (2016) in the same field at the Universidade da Beira Interior, Portugal. He is currently a Ph.D. student and researcher at the Instituto de Telecomunicações, Universidade da Beira Interior, Covilhã, Portugal. His research interests include geometric computing, point-based graphics, and visualization.
Contact: quochcmvn@gmail.com

**Acácio F. P. P. Correia** is a student who recently finished Master’s Degree in Computer Science and Engineering, at the Universidade da Beira Interior, and his dissertation focused on the study of natural language processing techniques and scientific document suggestions according to the context. He has previously completed Bachelor’s Degree in Computer Science and Engineering, at the same university. His professional interests include procedural generation, artificial intelligence, natural language processing, cryptography, and video game development.
Contact: acaciofilipe.correia@gmail.com

**Filipe Manuel Clemente** is Assistant Professor in Instituto Politécnico de Viana do Castelo, Escola Superior de Desporto e Lazer (Portugal) and researcher in Instituto de Telecomunicações, Delegação da Covilhã (Portugal). He has a Post.
Doc. in social network analysis applied in team sports in Instituto de Telecomunicações (2016). He has a Ph.D. in Sport Sciences—Sports training in Faculty of Sport Sciences and Physical Education from University of Coimbra (2015, Portugal). His research in sports training and sports medicine has led to more than 130 publications, 43 of them with impact factor (indexed at JCR). He has conducted studies in performance analysis, match analysis, computational tactical metrics, network analysis applied to team sports analysis, small-sided and conditioned games, physical activity, and health and sports medicine. He was guest editor of Science in Soccer special issue at Human Movement (2017), on Sports Performance and Exercise collection in Springer Plus journal (2015 and 2016) and on Performance in Soccer special issue at Sports mdpi journal (2016). He is also editor in three more scientific journals and reviewer in nine journals indexed on Web of Knowledge.
For further details see: www.researchgate.net/profile/Filipe_Clemente
Contact: filipe.clemente5@gmail.com

Fernando Manuel Lourenço Martins is Professor and Course Director of Basic Education of the Department of Education at the Escola Superior de Educação—Instituto Politécnico de Coimbra (Portugal) and research Member and Scientific Coordinator of Applied Mathematics group in Instituto de Telecomunicações, Delegação da Covilhã, Portugal. He has a Ph.D. in Mathematics in Universidade da Beira Interior (Portugal). His research in applied mathematics and statistical analysis has led to more than 190 publications. The research included advances in network analysis applied to team sports and assessment of interactions between children, statistical analysis in team sports and mathematical and statistical knowledge for teaching. He was coeditor on Sports Performance and Exercise collection in Springer Plus Journal.
For further details see: https://www.it.pt/Members/Index/1877 and www.researchgate.net/profile/Fernando_Martins13
Contact: fmlmartins@ubi.pt
Acronyms

CB Center-Back
CF Center-Forward
CM Center-Midfielder
DBMS Database Management System
DHT Discrete Hilbert Transform
DM Defending Midfielder
GK Goalkeeper
GPS Global Positioning System
LB Left Back
LPM Local Position Measurement
lpwratio Length per Width Ratio
LW Left Winger
PATO Performance Analysis Tool
PTZ Pan–Tilt–Zoom
RB Right Back
RMSE Root Mean Squared Error
RW Right Winger
SSG Small-Sided Game
uPATO Ultimate Performance Analysis Tool
Chapter 1
Network Analysis Tools

1.1 Introduction

Network analysis tools are used in a wide range of applications, for example, for the study of the structure and dynamics of social or infrastructure networks (e.g., a computer network or a telecommunication network). The social networks are everywhere and they can be formed of anything like a project team, classmates in school, sports teams, membership in social networks, etc. Thus, network analysis tools are more and more used to analyze the influence and interdependence of each element in a network. On the graph of a social network, people are considered as the nodes, and their connections or relations are the edges that connect the nodes.

Graph theory provides the mathematical support for the analysis. A graph consists of a set of nodes and their connections. The representation of the data for the formation of the network, in graph theory, occurs through matrices \([1, 4]\). Figure 1.1 presents a weighted digraph and their matrix associated. Note that in case of team sports analysis, the representation of the network corresponds to a weighted digraph if the direction and the number of interactions is a criteria. For example, in the case of the football, it is analyzed the passes between teammates and if the player A pass to the player B it is different if player B pass to the player A.

1.2 A Brief Review on Software Tools

This section includes a brief review on a set of software tools used in the analysis of networks. The review includes a description of the tools and of its capabilities.

NetworkX is an open source Python package which provides an API for the creation, manipulation, and study of complex networks \([15]\). The networks can be represented in graphs, directed graphs, multi-edge graphs, or multi-edge directed
graphs. The graphs can be analyzed and processed by algorithms which include approximation, clustering, and shortest path functions, among many others. Even though its main goal is the analysis, NetworkX also provides methods for the visualization of graphs.

igraph is a collection of network analysis tools [11]. According to the authors, igraph was created in order to efficiently process large graphs, be embedded into high level programming languages, and be used both interactively and non-interactively [5]. igraph is open source and it can be used in R, Python, C, and C++. Some of the functionalities provided in igraph include graph generation, Centrality measures, path length based algorithms, among others [5].

Gephi is a network exploration tool, which allows users to visualize networks as graphs, using layout algorithms [8]. Its main functionalities include data filtering, clustering, adding annotations, and calculating statistics [2]. Layout algorithms are used in the representation, improving the visualization, and organization of the nodes, mainly in large networks. It allows users to interact with the representation, manipulate the structures, shapes, and colors to reveal hidden patterns. Other features include an animation of how the network was created over time and the existence of a plugin center, which should provide users with additional functionalities [8].

Pajek is a program package for both analyzing and visualizing networks, including large networks [3, 17]. Pajek provides functionalities for extracting subnetworks, clustering, calculating statistics, and many others. Similarly to Gephi, Pajek also resorts to layout algorithms for optimizing the representation of the networks. There is another version of Pajek, called PajekXXL, which was designed with a special focus on large networks, reducing the memory usage and speeding up processing time [13].

Cytoscape is an open source software platform developed for visualizing networks in biological research. However, it works in the analysis and visualization of any type of network [6]. Even though it is a visualization focused tool, it provides some network analysis tools and is compatible with “Apps” (plugins) which can include other features. Its features include importation and exportation from other tools, such as igraph and Bioconductor, clustering, filtering, and compatibility with other alphabets besides the Latin one [6, 18].
Social Network Visualizer (SocNetV) is an open source tool designed for the analysis and visualization of networks. The tool provides functionalities for the calculation of standard graph theory and network cohesion metrics [7], clustering algorithms, and others. The visualization provides different options of layout for the representation of the networks. Extra features include the recreation of famous data sets and a Web Crawler capable of creating a network of all links available in a website [7].

NetworKit is a tool that is more oriented for large-scale network analysis. Its aim is to provide tools for the analysis of large networks that can range from thousands to billions of edges. For this purpose, it implements efficient graph algorithms many of them in parallel using multi-core architectures [14].

NodeXL Basic is a free, open source template for Microsoft Excel and NodeXL Pro offers additional features providing easy access to social media network data streams and advanced network metrics. NodeXL is a tool to explore networks graphs in Excel. It allows to enter a network edge list in a worksheet, click a button, and see the corresponding graph, all in the familiar environment of the Excel Window [10, 16].

Graph-tool is an efficient Python module for manipulation and statistical analysis of networks (i.e., graphs). Many algorithms are implemented in parallel, which provides excellent performance on multi-core architectures, without degrading it on single-core machines. Besides, it is a powerful visualization tool with a great variety of algorithms for graph representation [9].

Most of the tools described above are not capable of analyzing weighted networks or do not produce the expected results. Those that are capable of analyzing weighted networks, they are very limited in the terms of available metrics or simply ignore the weight of the edges, transforming the network into an unweighted network.

Given the nature of team sports, these are, usually, represented as weighted directed networks in order to preserve the information regarding the frequency and importance of interactions between players (i.e., each node is a player and its edges contain the frequency of interactions between players). This information, contained in the weights of the edges, is fundamental in the study of how well the team works.

uPA TO [12] was developed with this necessity in mind, providing users with a tool capable of calculating metrics for all types of networks (unweighted graphs, weighted graphs, unweighted digraphs, and weighted digraphs).

In Chap. 2, you can find an overview of uPA TO application where the main modules of the tool are presented. Chapter 3 presents the pseudocode of the individual measures that are available in the uPA TO. Chapter 4 presents the pseudocode of the collective and subgroup measures. Finally, Chap. 5 present a case study with real data, and for that, the match between PSG and Real Madrid during the UEFA Champions League of 2015–16 was chosen for our analysis.

More details about uPA TO can be found in the website of the application: http://upato.it.ubi.pt/.
References

Chapter 2
uPATO—Overview of the Application

2.1 Network Manipulation Modules

This section presents a description of the network modules of the uPATO that allow the user to: create an adjacency matrix that represents the network; visualize the network; calculate a set of metrics over the network; and visualize the results. Each one of these options will be described in the following sections.

The uPATO application is available in the website http://upato.it.ubi.pt. In the first page, the user can access the Modules, Publications, Contact, and Sign In options (see Fig. 2.1). But to use the uPATO, the user must register first. The registration process is quite simple, it requires that the user defines a name, username, email, and password. Besides, the user must confirm that cites the uPATO software in their publications when including any material produced with the tool (see Fig. 2.2). After that, the user can log in into the application and use it. Note that the login window has the option keep me logged-in (as shown in Fig. 2.2) which the user must select so that their connection to the server does not expire after 10 minutes.

2.1.1 Creating Network

The creation network option allows the user to create an adjacency matrix that represents the network. Thus, the user must select if he/she wants to create a matrix for team sports analysis or a general matrix. The creation of general matrices is limited to 100 nodes, even though the calculation of metrics can be used for bigger networks. For team sports analysis, the user can choose the type of the field, for example, football, basketball, etc. These options are available in the category and field option as shown in Fig. 2.3.
The general idea of the uPATO tool is to innovate in the way how match analysis is performed and used in team sports, for example in football. The uPATO tool allows the introduction of data based on adjacency matrices and integrates the several metrics used for team sports analysis. Usually, each author presents a tool with their metrics but the uPATO tool integrates all metrics available for graphs and digraphs, weighted or not.
In the case of team sports, the user can choose the dimension of the network by choosing the number of players (nodes) for each team. This means that our tool allows the creation of both networks, one for each team. The user can also choose whether the direction matters or not in case the network corresponds to a graph or a digraph. For example, in football, if the user wants to codify the passes between teammates then the direction matters, which means that the network that represents the sequence of passes is a weighted digraph because we want to analyze also the frequency of the passes. Besides, in the case of team sports, the user can also register the play endings. For example, when a player loses the ball, the ball goes out of the field or the play is interrupted by a foul. This kind of information is also very useful for the coaches to understand better what happened during a match in addition to the sequence of passes that gives the information about the players more influential. The user can also choose the symbols that are used to represent the players such as a simple square or a shirt. Figure 2.4 shows the options available in the tool.
After making their choices, the user can open the editor where he/she can position the players on the field. This option allows the user to position the players in a predefined tactic and define labels for each one. By default, the players have a sequential label between 1 and $N$, where $N$ is the dimension of the network.

Figure 2.5 shows the interface for the creation of the matrix associated with the first team. Note that in this case, we used the football to exemplify how to create the network that represents the sequence of passes.

Several options available to configure the team (i.e., our network) are displayed in the top right of the window. Thus, the first option, from the left to the right, allows the user to change the team (each team has a different color). The second option allows the change of the position of the current team to the other part of the field (i.e., normally, the teams change their positions in the field between the two parts of the game). The third option allows the user to position the players on the field and the fourth option allows the change of the label of each player. Figure 2.6 shows the results of the four options referred. The remaining two options are to save the matrices created to a file and to exit from the editor.

After having positioned the players in the field and personalized their labels, the application can be used to codify the passes between teammates to generate the network. Thus, to codify a pass, the user must click on the player that does the pass and then on the player that receives it. This feature was developed specifically for team sports, where the user can register, in real time, the interactions, for instance passes, between players.
Each player (node) is represented by a button, and a pass between two players is registered by pressing the button of the passing player followed by the button of the receiving player. The sequence of passes is displayed in the bottom of the window and it can be edited. For example, it is possible to remove the last pass or even delete an entire sequence. These options are available in buttons Remove Last or Delete, respectively. The button Add allows the user to insert a sequence of passes into the matrix, i.e., to the network. Every time the user adds a sequence of passes and has chosen the option to register the play endings, the application will show different options for the play endings, as can be seen in Fig. 2.7.

At any time, the user can save their matrix to a file in order to use it as a network for analysis and visualize in the other modules of the tool. This option allows the user to save a matrix of the network into different instants of time (see Fig. 2.8). For example, if the user wants to analyze the first and second parts of the game in
Add a sequence of passes and select the cause that ends this sequence.

Fig. 2.8 Saving a matrix and visualizing the graph/digraph associated a separate way. Besides, the user can also visualize the graph/digraph associated to each matrix saved or to the global matrix. Note that the global matrix is the sum of the saved matrices.

This feature to create a network was first introduced in the initial version of uPATO (named Performance Analysis Tool (PATO)) [2, 4].

Note that the uPATO can be used to create a network as explained above, but the network can also be imported from a file in the *.rtf format. In this case, the file must have the adjacency matrix that represents the network, which is always a square matrix. In the football, the rows correspond to the players that do the passes and the columns of the players that receive the passes. Note that the elements of the diagonal of the matrix are always zero because a player does not pass for itself.
2.1 Network Manipulation Modules

Fig. 2.9  Load the positions from file

2.1.2 Displaying Network

Even though the focus of the uPAT0 is the calculation of metrics, a simple representation of the graph is also provided. For that, the user must load the matrix that represents the network from a file as shown in Fig. 2.9.

In the case of a digraph, its representation can be subdivided into three categories: out, in, and in-out. The digraph-out correspond to the passes effectuated by players, while digraph-in are the passes received by the players. The digraph-in-out combine the two types of passes, giving an overview of the most influential players.

The representation of the graph/digraph can have the same configuration defined when creating the network.

Figure 2.10 shows the representation of the digraph-out and digraph-in. Note that these representations use the players position (nodes) like the tactical configuration defined for the network. But for that, the user needs to load another file where was saved the tactical positions of the players, as shown in the bottom of the Fig. 2.9. If the user does not have a file with the players’ positions, the graph representation put the players in a circle, as shown in Fig. 2.11.

However, the user can always select a node (player) and reposition it by clicking and dragging it. In addition, the user can select a node (player) and see only the nodes (players) that interact with it by double-clicking on the node. To see the complete graph/digraph again, the user must double-click in the window (i.e., out of the nodes). For example, Fig. 2.12 shows the subgraph-in and subgraph-out for the node 6. Note that the color of the edges indicates the number of passes. Thus, a dark color represents a greater number of passes than a light color.
2.1.3 Calculating the Metrics

uPATO allows to calculate metrics in both weighted and unweighted networks and separates metrics into three major categories:

- individual metrics—metrics that describe each individual node separately, providing a means for comparing nodes;
- subgroup metrics—metrics that describe the interaction between each one node and every other node;
- team metrics—metrics that analyze the team as a whole.
2.1 Network Manipulation Modules

Fig. 2.12  Subgraph in and out for node 6

![Subgraph in and out for node 6](image)

To calculate the metrics, first, the user needs to load the file with the adjacency matrix that represents the network, as shown in top of Fig. 2.13. Then, he/she has the possibility to select which nodes (i.e., players) and metrics that need to be calculated, as shown in the bottom of Fig. 2.13.

When the user presses the Calculate button, a new screen appears on which the user can see the results. This feature is described in the next section.
In the following chapters, the metrics available in the tool will be presented, as well as their codification. Besides, the metrics for social network analysis applied to team sports analysis are described in a previous publication [1].

2.1.4 Presenting Results

This option allows the user to see the values calculated for the selected metrics. The values can be presented in a table or in a chart.

Figure 2.14 shows the several matrix files used for the calculations and in front of each one (i.e., in Action column) the user has three buttons: Charts, Table, Delete. The Charts button allows the visualization of the results in a bar chart or into a box chart. The Table button presents the results in a table of values and the user can also export these data to a file using the button on the right top of the window (see Fig. 2.16). Finally, the Delete button allows the deletion of the results for a network.

Figure 2.15 shows the two examples of charts available to presents the results, which allow the comparison of the results between players for a set of metrics (bar chart) or see the performance of players for each metric (box chart). Note that for an easier comparison using a chart, the user must select the results of the metrics standardized by max value. Thus, all values are in the range [0..1].

In Fig. 2.15, the bar chart presents the results for players, 2, 3, and 4 for the Degree Centrality, Closeness Centrality, and Stress Centrality measures. If the user clicks on the label associated with each player, he/she can turn on or off this player into the chart representation (Fig. 2.15).
2.1 Network Manipulation Modules

Fig. 2.15  Type of charts available to present and compare results

![chart](image1)

![chart](image2)

In the top of Fig. 2.14 exists another button Play Ending Results that allows the user to display other results about the network beyond the values of the metrics. These results are related to the play ending conditions if they have been considered in the creation of the network. In this case, the user must load the file with the play ending conditions and can load also the file with the tactical configuration of the team. Figures 2.17 and 2.18 show the charts presenting the play ending conditions. Similarly, the user can select one or more results to display. Thus, he/she must click on the label of the result, which allows to enable or disable it from the chart.

In Chap. 5, a case study and their results presented using the options available in this tool will be described.

<table>
<thead>
<tr>
<th>Team Metric</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Links</td>
<td>417</td>
</tr>
<tr>
<td>Network Density</td>
<td>0.2106</td>
</tr>
<tr>
<td>Average Distance</td>
<td>0.2371</td>
</tr>
<tr>
<td>Network Diameter</td>
<td>0.4667</td>
</tr>
<tr>
<td>Network Heterogeneity (Coefficient of Variation of Vertex Degrees)</td>
<td>0.4341</td>
</tr>
<tr>
<td>Normalized Network Heterogeneity</td>
<td>0.9124</td>
</tr>
<tr>
<td>Variance of Vertex Degrees</td>
<td>270.8099</td>
</tr>
<tr>
<td>Transitivity</td>
<td>0.268</td>
</tr>
<tr>
<td>Reciprocity</td>
<td>0.7146</td>
</tr>
<tr>
<td>Group Degree Centralization</td>
<td>3.4333</td>
</tr>
</tbody>
</table>

Fig. 2.16  Table with the results of the metrics selected
Fig. 2.17 Chart with the play ending conditions

Fig. 2.18 Chart with the interceptions and foul conditions for the two teams
References


Chapter 3
uPATO—Individual Measures

3.1 Centrality

The Centrality is related to the number of edges associated with a node, without a special regard to the direction of the edge [18].

Included in this category, and described in this section, are the metrics: Degree Centrality (Sect. 3.1.1), Closeness Centrality (Sect. 3.1.2), Stress Centrality (Sect. 3.1.3), Betweenness Centrality (Sect. 3.1.4), Eccentricity Centrality (Sect. 3.1.5), Eigenvector Centrality (Sect. 3.1.6), Subgraph Centrality (Sect. 3.1.7), Laplacian Centrality (Sect. 3.1.8), PageRank Centrality (Sect. 3.1.9), Power Centrality (Bonacich’s) (Sect. 3.1.10), and Centroid Centrality (Sect. 3.1.11)

3.1.1 Degree Centrality

Degree Centrality (also referred to as Out-degree Centrality in the case of digraphs) is, like all measures of Centrality, a measure of how central a node is, i.e., it will represent how important a node is for helping in connecting nodes to one another [18].

In terms of team sports, this means that high Degree Centrality players are responsible for making many passes to other players, which could mean that they are more influential players in the team, than those players with smaller Degree Centrality [11].

This metric was implemented following Pseudocodes 2 and 3, which were based on Definitions 4.1, 4.2, 4.3, 4.5, 4.6, 4.7, and 4.8 from [5].
Pseudocode 1: Degree Centrality

Data: Adjacent matrix $M$ of the graph and number of nodes $nn$

Result: Degree Centrality $dc$ of vertices in the graph

1. Initiate $dc$ array with $nn$ positions containing 0;
2. for $i \leftarrow 0$ to $nn$ do
3.     for $j \leftarrow 0$ to $nn$ do
4.         if $i \neq j$ then
5.             $dc[i] \leftarrow dc[i] + M[i][j];$
6.         end
7.     end
8. end
9. return $dc$;

Pseudocode 2: Standardized Degree Centrality for unweighted graphs and unweighted digraphs

Data: Adjacent matrix $M$ of the graph (or digraph) and number of nodes $nn$

Result: Standardized Degree Centrality $sdc$ of vertices in the unweighted graph

1. Initiate $sdc$ array with $nn$ positions containing 0;
2. Calculate the Degree Centrality $dc$ of vertices in the graph;
3. for $i \leftarrow 0$ to $nn$ do
4.     $sdc[i] \leftarrow dc[i]/(nn - 1);$ 
5. end
6. return $sdc$;

3.1.2 Closeness Centrality

Closeness Centrality measures the geodesic distance of the connections of a node to all other nodes. As described in [8], in order for a node to be considered central, it needs to be able to quickly interact with all other nodes. The Closeness Centrality is inversely proportional to the distance, with high values of Closeness Centrality being related with nodes that have a low distance to all other nodes [3].

In terms of team sports, it means that a player with a high Closeness Centrality has performed many of his team’s passes, suggesting he is responsible for distributing the ball.

This metric was implemented following Pseudocodes 4 and 5, which were based on Definitions 4.10, 4.11, 4.13, and 4.14 from [5].