

Scientific Collaboration Network Analysis: A Brazilian Computer Science Graduate Programs Case

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Research

Keywords: design science research, information system, scientific collaboration, social networks

Posted Date: May 6th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-469721/v1>

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RESEARCH

Scientific Collaboration Network Analysis: A Brazilian Computer Science Graduate Programs Case

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Abstract

Scientific collaboration networks can present different views of researchers' interaction. The analysis of these networks allows research transparency focusing on the understanding of how science evolves in different contexts. In this article, we present a scientific collaboration network analysis using social network metrics as *average degree*, *connected components*, *betweenness* and *closeness centralities* applied to five Brazilian Computer Science graduate programs. An online artifact built upon the design science research paradigm, namely SCI-synergy, was developed to ease the analysis involving publication data available on the Digital Bibliography & Library Project (DBLP) from the graduate program members allied to the Federal University of Minas Gerais (UFMG), the State University of São Paulo (USP), the Federal University of Rio Grande do Norte (UFRN), the Federal University of Amazonas (UFAM), and the University of Brasília (UnB). The objective is to analyze the scientific collaboration network of each program focusing on the researchers' collaboration to understand patterns considering intra- and inter-program relationships. The analysis covers two database updates of 2019 and 2021. Results show that intra-program relationships are not always bigger among the highest-ranked programs in CAPES. Nevertheless, UFMG presents a greater total of cooperation among the five programs indicating research leadership and good inter-program collaboration patterns. We advocate that the collaboration network analysis using an online artifact can be useful to understand patterns of all the Brazilian Computer Science graduate programs to discover new research perspectives to be improved, avoided or even applied to other contexts.

Keywords: design science research; information system; scientific collaboration; social networks

Introduction

The scientific production process currently requires strategies to interconnect and enrich the different perspectives and interdisciplinarity in science. Information sharing, the joining of competencies, and the union of researchers' efforts to pursue common goals impel the production of knowledge [1]. Besides, the association of different points of view may generate new perspectives in research that combined with technology and connection facilities might lead to an increase in the number of collaborations among individuals geographically dispersed [2]. These factors contribute to the current appreciation for researchers who are capable of forming productive scientific collaboration networks.

As the number of studies and scientific publications increases, the interest in analyzing these collaborations augments. Regardless of specificities, it is possible to affirm that the co-authoring of artifacts generated by scientific activity, particularly of publications, is an indicator of collaboration [3, 4, 5]. Also, co-authorship exploration can be useful to reveal the flow and pattern of knowledge integration since the relationship between the authors might serve for scientific collaboration network analysis.

Co-authorship studies cover many research contexts verifying differences between academic and technical collaborations [6], collaboration characteristics in disciplines and between researchers from several institutions or countries [7, 8, 9, 10, 11, 12]. These studies confirm that authors collaboration has increased in science. Other studies demonstrate that international cooperative work has a greater impact and visibility increasing researchers' productivity [13]. Related to the inter-institutional research collaboration as a channel of open innovation, it boosts the flow of knowledge and technology between actors of an innovation system [14, 15, 16].

This work focus on Computer Science graduate programs allied to Brazilian universities. Brazilian Computer Science has long studied their graduate programs as presented in a seminal work [17], and posterior works [18, 19, 20]. Focusing on collaboration networks, in [21] authors use a quantification method based on the Gini coefficient to analyze scientific collaboration in research networks. In previous works ([22, 23]), we present a collaboration network analysis as a management tool using publication data available in Lattes Platform from one Computer Science graduate program in Brazil, including a recommendation module for scientific partnerships. Besides, many international works are leading to interesting findings as in [24] that explores how collaboration in Computer Science evolved since 1960, measuring influences of scientist groups based on multiple types of collaboration [25], and a cross-disciplinary research work presenting a survey of scientific teamwork collaboration [26]. Nevertheless, there is a research gap concerning the Brazilian Computer Science graduate programs with intra- and inter-scientific collaboration analysis.

Therefore, this work builds upon the fact that information related to the researchers' publications in their respective graduate programs with intra- and inter-program partnerships are not usually available online. Thus, the assumed hypothesis is that the use of online scientific collaboration network artifacts may help in promoting transparency of co-authorship. The resulting information might help researchers and institutions to analyze collaborative relationships to improve research policy decisions. For example, institutions may implement initiatives to foster the development of potential research collaborations with common interests but geographically distant to reduce regional disparities or increase internationalization.

In this context, we present a scientific collaboration network analysis using social network metrics through an online artifact, namely SCI-synergy. SCI-synergy was established over the design science research paradigm as an important methodology for information systems. The source data is from five Computer Science graduate programs linked to Brazilian universities focusing on the co-authorship relation in publications indexed by the Digital Bibliography & Library Project (DBLP) [27]. The graduate programs are located at five different states in Brazil illustrating the variety of characteristics of the country's research in the area: the Federal University of Minas Gerais (UFMG), the State University of São Paulo (USP), the Federal

University of Rio Grande do Norte (UFRN), the Federal University of Amazonas (UFAM) and the University of Brasília (UnB). The graduate programs were analyzed using social network metrics as *average degree*, *closeness* and *betweenness centralities*, and *connected components* (union-find or community detection).

Considering the social network partnership's analysis, our investigation focuses on the following research questions (RQ):

- RQ1. How is the scientific collaboration network of each graduate program?
- RQ2. How cooperative is each researcher in the graduate program?
- RQ3. What are the intra- and inter-program collaboration patterns?

The remainder of the article includes the Research Approach section with aspects of the design science research paradigm. The Scientific Collaboration Network Analysis and Discussion sections present answers to the three research questions with the Brazilian Computer Science graduate programs case. The literature review in the Related Work section, and final remarks in the Conclusion section.

Research Approach

This work was conducted under the Design Science Research (DSR) paradigm [28, 29, 30]. DSR is derived from the engineering discipline and depicts the science of the artificial that bridges practice and theory through a conceptual framework to research in information system [31]. The DSR is a key factor for a new and innovative research paradigm since it has proven to produce practically relevant research results aiming to ensure rigor and relevance in prototyping research projects [32].

The DSR advocates the development of an artifact through the knowledge base (fundamentals and methodologies) to validate the theory that is being defended in the information system research while satisfying the existing environment's context and constraints including people, organizations, and technology. In the sequence, we present the DSR paradigm illustrated through the elements of the conceptual framework related to the SCI-synergy artifact construct.

Knowledge Base

Knowledge base relates to the definition and discussion of the fundamentals and methodologies adopted in the research. It represents the knowledge applied to the research to guide the construction of the artifact [32]. In the sequence, the topics used as knowledge in this research are presented.

Social Networks

The scientific study of networks is broadly interdisciplinary including computer networks, social networks, and biological networks [33]. Social networks have received an enormous amount of interest in the last few years through the use of technology in platforms such as Facebook, Instagram, and others, having important breakthroughs in the social sciences field.

According to the fundamentals of graph theory, a social network can be represented by a graph $G = (V, E)$, where V is the set of vertices that denotes individuals under consideration, and E are the edges corresponding to a set of existing relationships between these individuals (e.g., friendship, parenthood or professional collaboration). Relationships can have different intensities that reflect the strength

of social connections and their intensity is usually represented by a function $w(e)$ with $e \in E$, which associates a weight as a property of an edge in the graph.

Scientific collaboration networks are in essence social networks where relationships represent some type of scientific interaction. In this work, we are interested in a specific network, where the vertices correspond to authors of scientific publication and the edges (with weights) express how much two authors have collaborated in the authorship of articles. In this regard, there are wide-open platforms such as ResearchGate with over 15 million registered researchers and 118 million publications. But such platforms do not provide transparency of scientific collaboration through graphical views with social network metrics to understand the existing relationships through intra- and inter-program perspectives.

Network Metrics

With the structure of a network, it is possible to compute a variety of measures that represent particular features of the network topology. In the literature, there are standard measures and metrics for quantifying network structure including degree centrality, Eigenvector centrality, Katz centrality, transitivity, reciprocity, and similarity. Some social network metrics first introduced to compute aspects of the network relationships are now in wide use in many other areas [33]. In this work, we assume the network centrality concepts according to [34]. The following metrics are used to allow the analysis of co-authorship relationships:

- *average degree* or *degree of vertices* computes the average number of relationships of each node in the graph by the sum of adjacent edges divided by the number of vertices as presented in Equation 1. Let $N = |V|$ be the number of nodes, and $L = |E|$ be the number of edges, the *average degree* of a network is given by:

$$Avg = \frac{\sum_{i=1}^n deg(i)}{N} = \frac{2L}{N}. \quad (1)$$

The *average degree* highlights how connected the network is. With a low *average degree*, there are many isolated nodes, while, a high score tells that there are many relationships among nodes (i.e., high collaboration). The *average degree* presents the overall profile of each university graduate program network. This measure can be used to find very connected or collaborative researchers who may easily connect with the wider network of researchers.

- *connected components* or *union-find* describes disjoint sets of connected nodes in the network detecting smaller research groups or communities. This measure gives us a picture of how big and how many communities there are in the network. These communities can be inside a graduate program (intra-program view) or among graduate programs from different universities (inter-program view).
- *betweenness centrality* calculates the shortest path through a network between two vertices (i.e., geodesic path) using Equation 2 and the breadth-first search algorithm. Let $n_{s,t}^i$ be the number of geodesic paths from s to t that pass through i and let $n_{s,t}$ be the total number of geodesic paths from s to t . The

betweenness centrality of vertex i is:

$$b_i = \sum_{s,t} w_{s,t}^i = \sum_{s,t} \frac{n_{s,t}^i}{n_{s,t}}, \quad (2)$$

where by convention the ratio $w_{s,t}^i = 0$ if $n_{s,t} = 0$. This measure shows researchers that can act as ‘bridges’ between nodes in a network, which is a way to find members who can influence the flow around a system.

- *closeness centrality* calculates the shortest paths between all nodes as presented in Equation 3 since nodes with a high closeness score have the shortest distances to all other nodes being useful to find researchers best placed to influence the entire network quicker. Suppose $d_{i,j}$ is the length of a geodesic path from i to j , meaning the number of edges along the path. Then the *closeness centrality* for vertex i is:

$$C_i = \frac{n}{\sum_j d_{i,j}}. \quad (3)$$

Name Disambiguation

In the context of scientific social networks, one challenge is to check whether authors correspond to the same individuals. Although there is a whole area of research on automatic disambiguation of author names [35, 36, 37], we apply traditional techniques available at the DBLP that include homonyms and synonyms treatment. A homonym is one of a group of words that share the same spelling but have different meanings. In DBLP different authors with the same name are homonyms. Thus, the same name refers to the same (Latin-1) string, taking punctuation (e.g., "O'Shea" and "O-Shea"), diacritics (e.g., "Æleen" and "AEleen"), and case ("Gianluigi" and "GianLuigi") into account to consider different names.

In DBLP digital bibliography repository, authors’ data is represented by their page. Authors are assigned a unique key and their names are distinguished in the database by a unique numerical suffix. At the moment, the splitting of existing DBLP author pages is either triggered by requests of authors or if the DBLP team can prove that there are several persons behind an entry. Unfortunately, in many cases, homonyms remain undetected needing further investigation.

There are many reasons why several author names are considered to be synonymous for a particular author: name changes, nicknames, sporadic use of middle names, missing or abbreviated name parts, or even pseudonyms. Different spelling, misspelling, or mistranslation are also causes of author name synonym [38]. Occasional spelling errors in the publishers’ metadata also complicate the matter.

When multiple versions of a name are frequently used on publications, these names may be included as aliases to the DBLP data set and we used those in the SCI-synergy artifact. There are many techniques to deal with author name disambiguation such as string similarity metrics, e.g., Jaccard similarity, Levenshtein distance, term frequency-inverse document frequency (TF-IDF), and the Jaro-Winkler distance [39, 40]. In future work, we may use some other metrics associated with the DBLP author name disambiguation.

Environment

The environment in the DSR paradigm establishes where the information system research is being applied and to whom it wants to provide results and benefits. This work focuses on research institutions, more specifically, graduate programs allied to Brazilian universities using real data of five Computer Science programs.

In Brazil, every four years the graduate programs have the research and education quality assessed by a public agency within the Brazilian Ministry of Higher Education, the Brazilian Coordination for the Improvement of Higher Education Personnel (CAPES)^[1]. CAPES is responsible for the expansion and consolidation of graduate programs in the country. For that, it is constantly improving the assessment metrics. Nevertheless, there are some commonly used metrics such as the intellectual production that always compose the program's weight, a numerical value between 3 and 7. According to CAPES, a program which weight is 7 excels in their respective fields worldwide.

The Brazilian graduate programs' research policy focus on the increase of intra- and inter-program interactions encouraging cooperation with international senior researchers to achieve the highest level at the quadrennial assessment carried on by CAPES (last run 2013-2016). As presented in the Introduction section, the selected Computer Science graduate programs cover four different regions and five states in Brazil: in the Southeast region, Minas Gerais state, the UFMG (level 7 by CAPES), and in São Paulo state, the USP (level 6 by CAPES); in the North region, Amazonas state, the UFAM (level 5 by CAPES); in the Northeastern region, Rio Grande do Norte state, the UFRN (level 5 by CAPES); and in the Central-West region, Federal District state, the UnB (level 5 by CAPES). Since there are no level 7 and 6 Computer Science graduate programs in the North and Central-West regions of Brazil, we have chosen three programs level 5 to enable comparison among regions.

The researchers' information was captured from the websites of the graduate programs linked to the publications' authorship in the DBLP digital repository. Additional DSR environment details are presented in the Artifact Construct section focusing on technological aspects.

Artifact Construct

Considering the computational infrastructure used in the SCI-synergy artifact construct the architecture is presented in Figure 1. The architecture is composed of three modules encapsulating different requirements including data source (input), database storage, and collaboration network visualization (output):

- data collection from digital repositories - researchers information (authors name) from the graduate programs web sites (Uniform Resource Locator - URL), and authors' publications from the DBLP data source eXtensible Markup Language (XML);
- graph NoSQL database construction - consolidates all data collected from the other two repositories (web sites and DBLP);
- social network metrics - *average degree, connected components*. The *betweenness* and *closeness centralities* are compute based on [41];

^[1]<http://www.capes.gov.br/>

- visualization interface - the presentation of the scientific collaboration network views with intra- and inter-program, and researchers' information with collaboration chart and publication histogram.

The operationalization process is presented in Figure 2. The process begins with researchers' data collection from the university's graduate programs (web sites) using a Python script that receives the address of the page as input. The researchers' data collection includes the name (authors of publications), the Brazilian Curriculum Vitae platform called Lattes^[2] and the email (when available). The researchers' data is stored in a JavaScript Object Notation (JSON) file of the respective graduate program. These initial authors are called 'seeds' since it is from them that the publications with co-authors are filtered from DBLP records (retrieved in XML format). The 'seeds' are loaded on the graph database according to the conceptual data model presented in Figure 3. One important aspect to note is that the researcher's name in the graduate programs web sites should match with the author's name in DBLP, however, it is not what happens in all cases, and even using disambiguation techniques some information maybe get lost.

In parallel, publications data is recovered from the DBLP repository. A DBLP XML archive is obtained through the DBLP url^[3] being compressed in gzip format. Then, publications are loaded on the graph database whose authors are from one of the selected institutions ('seeds') and respective coauthors from other institutions. The DBLP name disambiguation of the authors' names is carried out as cited in the Research Approach section. The authoring attributes matching is then performed to create the scientific collaboration network (attribute name for vertices of type Author and attribute author for vertices of type Publication).

Finally, the graph visualization of the scientific collaboration networks is generated. Subsequently, the scientific social network graph is ready to be visualized through the online interface or using a tool like Gephi, graph visualization and manipulation software [42]. The graph presentation's purpose is to allow the visualization of the relationships between the researchers and how connected (the edge weight) they are with other groups. From the final database, several information and statistics focusing on researchers' collaboration are collected and presented.

The conceptual data model used in the graph NoSQL database is depicted in the form of a directed graph in Figure 3. The centered vertex «Author» represents the authors of each published article which using the *Write* edge relates to their respective articles («Article» vertex) that through the *Publish* edge relates to the «Journal» vertex. The relationship of each author with their respective university was modeled through the «Institution» vertex through the *Associated* edge and its relation to the graduate program («Program» vertex) to which the author is bound using the *Has* edge when the author is a researcher from one of the five universities used in the case. Authors may also be connected to other authors through *Co-Authoring* edge.

Technologies Summary

The artifact construct applied different technologies that helped to overcome the work challenges. One challenge was the storage of the collaboration network data in

^[2]<http://lattes.cnpq.br>

^[3]<http://dblp.uni-trier.de/xml>

a graph NoSQL database. For that the Neo4j was chosen since it has the best query performance in graph-based data models [43]. To execute analytical calculations and the generation of graphs, the Networkx library was used [44]. The Networkx implementation in Python allowed the integration with the software artifacts developed in this research. For the communication between the various modules implemented the JSON data format was adopted, since it is used for structured data representation, being very common in the development of Web services to the detriment of the XML format.

In parallel with the collection of the researchers of each graduate program, the DBLP publications data was obtained in the form of a single compressed XML file in the gzip format of 510 MB in size. When extracted the XML file consumed about 2.5 GB that was handled by XML parsers of Document Object Model (DOM) and Simple API for XML (SAX). SCI-synergy online artifact is available for use in <http://165.227.113.212> with the code available in the GitLab InfoKnow research group project repository (<https://gitlab.com/InfoKnow/SocialNetwork/aureliocosta-sci-synergy>).

Scientific Collaboration Network Analysis

The scientific collaboration network analysis using social network metrics as *average degree*, *connected components*, *betweenness* and *closeness centralities* were applied to five Brazilian Computer Science graduate programs using the SCI-synergy artifact. Considering the database update in 2019-12-27, the five programs include 179 members distributed as follows (decreasing order): 55 from UFMG, 38 from USP, 36 from UFAM, 26 from UnB, and 24 from UFRN. From the initial number of 179 researchers ('seeds'), the co-authors were added, resulting in 7,368 authors in the scientific collaboration network.

The names of the 'seeds' were used to filter the publications from the DBLP. These authors produced 7,203 publications between journal articles (2,229), conferences proceedings (4,961) and books (13). In total 13,962 vertices and 77,605 edges were loaded into the scientific collaboration network including authors and publications from the five Computer Science graduate programs together with co-authors from other institutions. A database update was done in 2021-02-03 for the five graduate programs that increase the number of members to (194) distributed as follows (decreasing order): 61 from UFMG, 37 from USP, 36 from UFAM, 31 from UnB, and 29 from UFRN. The total number of authors increased to 8,418, and publications to 8,757, with 3,030 journal articles, 5,711 conferences proceedings, and 16 books. Totalling 17,617 vertices and 92,287 edges in the network.

The SCI-synergy home page is presented in Figure 4 including available universities and number of researchers; the total number of graduate programs researchers, the total number of authors (researchers and co-authors), the total number of publications (detailed by books, journal, and in proceedings articles); and the intra and inter-program collaboration network among the five programs.

Research Questions Answers

RQ1. How is the scientific collaboration network of each graduate program?

Considering the four social network metrics used in the analysis, we applied the *average degree* to each graduate program to check how is the collaboration network. As presented in the *Network Metrics* section, a high *average degree* score tells that there are many relationships among nodes while many isolated nodes present a low score. Although it is a basic centrality measure to understand such potentially complex networks, we consider this metric can present the overall profile of each program focusing on how connected or collaborative researchers are in the scientific network. The first order neighborhood was used to calculate the *average degree* of each program, the co-authorship relation between the allied authors and their co-authors was considered for this metric.

Related to the database update in 2019-12-27, Table 1 presents the total network amounts including the number of researchers, co-authors, co-authorship relations, scientific production with the period, and *average degree* of each graduate program. Note that the average degree of each collaboration network varies from 4.58 to 2.76, which means that on average each author is connected to 4 and 2 others in the UFMG and USP programs, respectively. Considering that the computer science graduate program from UFMG is level 7 by CAPES, it is expected that the *average degree* of the researchers' network would be bigger than the other programs that are level 6 (USP) and level 5 (UFAM, UFRN, and UnB). Although UFMG and USP period of publication is almost the same, 1981 and 1980, respectively, the co-authors' number, co-authorship relations, and the total of publications are almost three times bigger in UFMG than in USP, resulting in USP's *average degree* of 60% of UFMG. It is interesting to note that the *average degree* of UFAM (3.78) is the highest among the three level 5 programs even with the least number of co-authors (895) and the total number of publications (819) meaning there is a well-connected network in the program with many collaborative researchers.

To compare the 2019 results to the 2021 database update, we present Table 2. Although the number of researchers had a little increase from 179 to 194, there are changes in the number of co-authors, co-authorship relations, total publications, and *average degree* of the programs. Note that the *average degree* of each collaboration network varies from 3.49 to 2.32 with the highest being UFMG with 3 and the other four with 2. The *average degree* of UFRN (2.83) is the highest among the other level 5 programs (UFAM, and UnB) and USP (2.45).

The *Scientific Network* menu option in SCI-synergy is illustrated in Figure 5 with the UnB graduate program highlighting the filters to refine the search by institution, researcher, and period (year). For each of the five programs, researchers appear with the same vertex color in the network differing from researchers linked to other programs using the colors presented on the SCI-synergy home page (Figure 4). The UFMG, USP, UFAM, UnB, and UFRN network views are presented in Figures 6, 7, 8 9, 10, respectively.

RQ2. How cooperative is each researcher in the graduate program?

The collaborations among researchers can occur in different ways. To check how cooperative each researcher is in the graduate program we used two centrality mea-

asures. The *betweenness centrality* allows finding the members that act as “bridge” between researchers in the collaboration network, or the researchers who influence the flow of knowledge in the scientific network. Table 3 presents the ten first researchers with the highest *betweenness centrality* score, their program association, CNPq researcher scholarship level, considering both database updates (2019-12-27 and 2021-02-03). The researchers’ names appear anonymized to maintain privacy, but can be accessed in Sci-synergy. The same name identification is kept in the *closeness centrality* in Table 4.

Considering the 2019-12-27 database update, six of the ten highest scores are from the UFMG program (60%). But considering the 2021-02-03 update, the participation of UFMG falls to 40%. These researchers receive the CNPq researcher scholarship varying from PQ 1A (the highest level) to PQ 2. It is interesting to note that some researchers are not associated with the five studied programs but from PUC-Rio, UFPA, UFRJ, Unicamp, and the University of Ottawa in Canada, who promote collaboration in the network.

Another centrality measure used to check how cooperative researchers are is the *closeness centrality*. This metric tells us who is the researcher that is closer to a major number of other collaborators in the social network and in this way can influence the entire network quicker. Table 4 presents the ten first researchers with the highest scores with their program association and CNPq researcher level, considering both database updates (2019-12-27 and 2021-02-03).

Considering the 2019-12-27 database update, nine of the ten highest scores are from the UFMG program (90%), where all researchers receive the CNPq scholarship varying from PQ 1A to PQ 2. However, in update 2021-02-03 the UFMG participation falls to 60% including a bigger diversity of programs (UnB, USP, UFRN). Considering the update 2019-12-27, although the score variation is small (from 0.3305 to 0.3017), it is interesting to note that two PQ 2 researchers have the highest *closeness centrality* scores than others with the highest CNPq scholarships. Also, an interesting fact happens with the 2021-02-03 update, where six researchers without the CNPq scholarship are better ranked than two PQ 1A researchers. This is a trait of *closeness centrality*, meaning these researchers can influence the entire network quicker.

Although the degree of internationalization is not the focus of this work, we illustrate in Table 5 aspects of collaboration occurring with one researcher of each Computer Science graduate program considering the 2021-02-03 database update. We included researchers that receive the CNPq scholarship level 1 (varying from PQ 1A to 1D) since they are expected to have the highest degree of internationalization. The aspects include scores of intra-program, inter-program, national (Brazilian co-authors), and international co-authorship with a relative score ($\text{Intl. (\%)} = \text{international}/(\text{intra-program} + \text{inter-program} + \text{national} + \text{international})$).

Since the DBLP digital repository does not include all researchers’ affiliations it was not possible to extract the degree of internationalization automatically, demanding manual treatment. Note the relative score presents a great variation among the researchers with the following decreasing order: (1) Name4 (UnB, PQ 1B) 67.64%; (2) Name2 (USP, PQ 1D) 40.19%; (3) Name1 (UFMG, PQ 1A) 16.27%; (4) Name5 (UFRN, PQ 1D) 13.57%; (5) Name3 (UFAM, PQ 1B) 5.98%. Thus, the highest

international co-authorship relative score is not allied to the highest CNPq scholarship. In future work, the degree of internationalization would be computed automatically with the inclusion of affiliation attribute in the database or the association of other databases that provide some affiliation attribute, e.g., ORCID^[4].

Individual collaboration aspects of the researchers can be viewed through filters in the SCI-synergy artifact as presented in Figure 12. Each edge on the network represents at least one relationship of coauthoring with the total amount appearing as the edge label.

There is also the *Find Researcher* menu option as presented in Figure 13. This option presents how cooperative the researcher is in the graduate program comparing to the highest, medium, and lowest coauthoring degree by a year. The total number and the name of coauthors are presented by year with the number of publications. An annual histogram of publications is presented in Figure 14. The search engine uses a full-text search index on researchers' names allowing queries with partial names.

RQ3. What are the intra- and inter-program collaboration patterns?

The intra- and inter-program research collaboration network views of the five graduate programs are presented in Figure 11 considering both database updates (a) 2019-12-27 and (b) 2021-02-03. In the relationships graph, the edge width represents the amount of collaboration between the institutions and the total amount appears like the edge label.

Tables 6a and 6b present the intra- and inter-program relationships of the graduate programs with two database updates. Considering the 2019 update and the inter-program relationships greater than ten, we note that there are 408 relationships between UFMG–UFAM, followed by UFMG–UnB (59), UFMG–UFRN (28), and UnB–UFRN (26). Thus, UFMG (level 7 by CAPES) presents a greater total of collaborations among the five Computer Science graduate programs indicating research leadership and good inter-program cooperation patterns. An interesting aspect is an absence of cooperation between some level 5 programs as UFAM–UnB, and UFAM–UFRN. Also considering the intra-program view the UFMG holds the highest collaboration score (3,290), followed by UFAM (684), USP (532), UFRN (464), and UnB (456). Thus, the intra-program relationships are not always bigger among the highest-ranked programs in CAPES as presented by the following decreasing order: UFMG (level 7), UFAM (level 5), USP (level 6), UFRN and UnB (level 5).

Considering the 2021 database update the relationship patterns are the same. If we consider relationships greater than twelve we note 410 collaborations between UFMG–UFAM, followed by UFMG–UnB (67), UFMG–UFRN (28), UnB–UFRN (27), UFMG keeps the collaboration leadership of the programs. Also, the absence of cooperation between UFAM–UnB, and UFAM–UFRN programs are kept. The intra-program view presents UFMG with the highest collaboration score (3,498), followed by UFAM (764), USP (564), UFRN (526), and UnB (512).

^[4]The ORCID iD is a unique, persistent identifier free of charge to researchers, available at <https://orcid.org/>

Considering the topological aspect of the network, we applied the *connected components* to check how big and how many communities there are in the network and validate whether the small world phenomenon [45] happens in this network. The identification component represents each research group in the network. In the SCI-synergy interface, by clicking on the id numbers it is possible to observe their participants. We present in Table 7 the first ten groups applying the *connected components* metric to the network formed by the five graduate programs with the two database updates (2019-12-27 and 2021-02-03).

Note that component 8 is formed by 6,933 inter-program members in 2019, representing the biggest group in the network. In 2021 (14 months later), the component 0 has 8,373 members (the same component 8 in 2019). Thus, the social network is more connected in the biggest group in 2021 than in 2019. Note also, that in 2021 there are only four groups with more than one component while there were eight in 2019.

Consulting the 2019 data, we verified that in the bigger component 8 with 6,933 members only 160 are linked to one of the five programs analyzed. The graph in Figure 15 presents the authors' participation in this bigger component. Considering the total of 179 members distributed as 55 UFMG, 38 USP, 36 UFAM, 26 UnB, and 24 UFRN, we checked the following distribution (decreasing percentage order): $51/55 = 92.73\%$ UFMG, $24/26 = 92.31\%$ UnB, $34/38 = 89.47\%$ USP, $21/24 = 87.50\%$ UFRN, and $31/36 = 86.11\%$ UFAM. Thus, UnB (level 5 by CAPES) has greater participation in the bigger group than USP (level 6), and UFAM has less participation in this group.

The graph in Figure 16 presents the authors' participation of the bigger component with 8,373 members (component 0) in 2021. Considering the total of 194 members distributed as 61 UFMG, 37 USP, 36 UFAM, 31 UnB, and 29 UFRN, there are 168 members linked to the programs in this component with the following distribution (decreasing percentage order): $37/37 = 100\%$ USP, $28/29 = 96.55\%$ UFRN, $58/61 = 95.08\%$ UFMG, $27/31 = 87.10\%$ UnB and $18/36 = 50\%$ UFAM.

Thus, the *connected components* metric indicates that most of the researchers are connected to the bigger groups in both years (6,933 - 2019, 8,373 - 2021). Also, there are many individual groups in the whole network as presented in Table 7. Besides, considering Figures 15 and 16, there are four programs with high participation in the bigger groups (USP, UFRN, UFMG, UnB). But in 2019 there is a more uniform participation distribution - UFMG 92.73%, USP 89.47%, UFAM 86.11%, UnB 92.31%, UFRN 87.50% - than in 2021 - UFMG 95.08%, USP 100%, UFAM 50%, UnB 87.1%, UFRN 96.55%. Considering the 2019 and 2021 results there are programs that increased participation in bigger group - UFMG, USP, UFRN and others that decreased participation - UFAM, Unb. Further investigation is necessary to drive conclusions related to the *connected components* composition.

Considering the researchers' cooperation in the graduate programs many aspects can be analyzed using the intra- and inter-program views of a scientific collaboration network. For example, the network results of Table 7 presents many individual groups which might reflect a specific characteristic of the graduate programs analyzed, but further investigation including other computer science programs can verify whether this is a national reality. However, we can confirm that this network

has a small world aspect with more than 98% of members in the bigger component or 8,373 members of 8,418 total researchers.

Discussion

Interesting results answering the research questions were presented in the Scientific Collaboration Network Analysis section. In this section, we present an overview of these results focusing on each Computer Science graduate program considering the two database updates (2019-12-27 and 2021-02-03) as put together in Tables 8a and 8b.

The highlights of each program network analysis include:

- the overall profile of the UFMG graduate program presents the highest *average degree* among the five analyzed programs - **4.58** in 2019 and **3.49** in 2021 - meaning that on average each researcher is connected to four and three other researchers, respectively (Tables 1 and 2). Checking the researchers who influence the flow of knowledge in the whole network, there are six in ten researchers with the highest scores from UFMG (**60%** of *betweenness centrality* in 2019, Table 3) and **40%** in 2021. Besides, checking how cooperative researchers are computing the *closeness centrality* we note that from the ten highest scores nine are from UFMG (**90%** in 2019 and **60%** in 2021, Table 4). Also, UFMG presents the highest intra-program collaboration amount with **3,290** in 2019 and **3,498** in 2021, and also inter-program with **498** in 2019 and **508** in 2021 (Tables 6a and 6b). The *connected components* of the UFMG program present the highest participation (**51/55= 92.73%**) in the bigger groups formed by 6,933 members in 2019, and **58/61= 95.08%** in 2021 (Table 7). Note that UFMG presents the highest results in five aspects reported in Table 8a. In special, it presents a high degree of *closeness* and *betweenness centrality* affecting other programs in their collaborative pairing. UFMG presents the highest intra-program collaboration (3,290 and 3,498) and inter-program collaboration, especially with the UFAM program (408 and 410). In summary, UFMG metrics confirm that the program is a good representative of the level 7 programs by CAPES.
- the USP graduate program presents the lowest *average degree* among the five programs - **2.76** in 2019 and the second lower in 2021 (**2.45**) - meaning that on average each researcher is connected to two other researchers (Tables 1 and 2). USP has one in ten researchers with the highest scores of *betweenness centrality* **10%** in 2019 and **0%** in 2021 (Table 3), and none in the ten highest scores of *closeness centrality* **0%** in 2019 and **10%** in 2021 (Table 4). Also, USP presents the third highest intra-program collaboration amount with (**532**) in 2019 and (**564**) in 2021, and the lowest inter-program amount with **23** in 2019 and **25** in 2021 (Tables 6a and 6b). The *connected components* of USP present a good level of participation in the bigger group of 2019 (**34/38=89.47%**) increasing to **37/37=100%** in 2021 (Table 7). USP is a level 6 program by CAPES presenting an *average degree* lower than the three level 5 programs in 2019 and lower than two in 2021 (UFAM, UFRN), indicating that the researchers are not very connected in the network. USP presents good intra-program collaboration, but very incipient inter-program

- collaboration with UFAM, UnB, and UFRN programs. USP presents a degree of *betweenness centrality* equal to UFAM and better than UnB and UFRN in 2019, but worse than UFAM in 2021. The *closeness centrality* of USP in 2019 is equal to the three level 5 programs and in 2021 equal to UFRN, worse than UnB and better than UFAM. USP presents the third-highest *connected components* score in the bigger group of 2019 and the best in 2021 showing a greater increase in the social network connection in a short period (14 months), while UFAM and UnB decreased their participation in the last year.
- the UFAM graduate program presents the highest *average degree* among the three level 5 programs by CAPES with **3.78** in 2019 and the second highest **2.63** in 2021 - meaning that on average each researcher is connected to three and two other researchers in the network, respectively, just like UnB and UFRN (Tables 1 and 2). Considering 2019, UFAM (like USP) has one researcher in ten researchers with the highest scores of *betweenness centrality* (**10%**, Table 3) and none in the ten highest scores of *closeness centrality* (**0%**, Table 4). However the participation of UFAM in top *betweenness centrality* is **20%** while in top *closeness centrality* there is no UFAM researcher in 2021. Also, UFAM presents the second highest intra-program collaboration amount with (**684**) in 2019 and **764** in 2021, and also the second highest inter-program amount with **418** in 2019 and **422** in 2021 (Tables 6a and 6b). The *connected components* of the UFAM program present the smallest participation in the bigger groups of 2019 (**31/36=86.11%**) (Table 7), getting worse in 2021 with **18/36=50%** of participation in the bigger component (Table 8b). UFAM presents the most recent publication period (1995-2019) among the five programs, with a concentrated inter-program collaboration with the UFMG program (**408**) (Table 6a) and **410** relationships (Table 6b). Considering 2021, UFAM (level 5 by CAPES) is better than USP (level 6) presenting two researchers in the hall of the ten highest *betweenness centrality* score who act as “bridge” between researchers in the whole scientific network, where one of them without CNPq PQ scholarship.
 - the UnB graduate program presents the lowest *average degree* among the three level 5 programs **3.04** in 2019 and **2.32** in 2021 - meaning that on average each researcher is connected to three and two other researchers in the network, respectively, just like UFAM and UFRN (Tables 1 and 2). UnB has none researcher with the ten highest scores of the *betweenness centrality* (**0%**, Table 3) in 2019 and 2021. Considering the top ten scores of *closeness centrality*, UnB has no researchers in 2019 **0%** increasing to **20%** in 2021 (Table 4). UnB presents the lowest intra-program collaboration amount with **456** in 2019 and **512** in 2021, but the third highest inter-program amount with **94** in 2019 and **103** in 2021 (Tables 6a and 6b). The *connected components* of the UnB program presents the second-highest score of participation in the bigger group of 2019 (**24/26=92.31%**) and the fourth of 2021 (**27/31=87.10%**) (Table 7). The UnB program is the most recent level 5 by Capes in the analyzed group (last quadrennial assessment carried on by CAPES 2013-2016). Nevertheless, UnB presents the highest inter-program collaboration amount compared to UFRN and USP. Also, UnB presents the highest score of participation in the

bigger group of 2019 than USP, UFAM, and UFRN demonstrating an effort to increase its scientific collaboration network, especially considering the internationalization aspect presenting the highest relative score with 67.64% (Table 5).

- the UFRN graduate program presents the second best *average degree* among the three level 5 programs in 2019 (**3.65**), and the second best overall in 2021 (**2.83**) - meaning that on average each researcher is connected to more than two other researchers in the network just like UFAM and UnB (Tables 1 and 2). Like UnB, UFRN has none researcher with the highest scores of the *betweenness centrality* (**0%**, Table 3) but one in the *closeness centrality* (**10%**, Table 4). Also, UFRN presents the second best intra-program collaboration amount among the level 5 programs with **464** in 2019, but the second lowest inter-program amount with **55** in 2019 and 56 in 2021 (Tables 6a and 6b). The *connected components* of UFRN present a good level of participation in the bigger group of 2019 ($21/24=87.50\%$) (Table 7) and this score is improved in 2021 ($28/29=96.55\%$) (Table 8b). The UFRN program is the smallest in the number of researchers, but with a good *average degree* (better than USP and UnB), intra-program collaboration score better than UnB, inter-program collaboration score better than USP, *connected components* in the bigger group of 2019 better than UFAM, even increasing in 2021 indicating a successful effort to have a well-connected collaboration network.

Related Work

The literature review highlight works that deal with collaboration aspects in scientific social networks and/or discuss the Brazilian Computer Science scenario. To analyze the works we elected a set of aspects stressing the aims of this research being inspired by the subjects addressed by the profile analysis of the top Brazilian Computer Science graduate programs [46]. The set of aspects were classified into six categories:

- *focus of the study* – studies concentrated on individual scholars, research groups or institutions.
- *geographic coverage* – the scientific network coverage, i.e., specific country or the world.
- *data source* – the data source is DBLP digital library or other platforms/sites (e.g., Lattes, Jems).
- *adopted metrics* – researchers' volume of publication, considers authors and co-authors, and social network metrics (e.g., *average degree*, *connected components*, *betweenness* and *closeness centralities*).
- *scope of the analysis* – the network properties, the adopted collaboration patterns, how temporal evolution is considered, how intra- and inter-program collaboration occurs.
- *implementation* – the artifact to analyze the scientific network is available online and the code accessible for anyone.

Considering the listed set of aspects, SCI-synergy was compared to nine research articles summarized in Table 9 and discussed in the sequence.

Focus of the Study

The focus of this research is not to evaluate the researchers' profile but to analyze their scientific collaboration network using social network metrics and the SCi-synergy online artifact. The analysis focuses on the researchers' collaboration considering intra- and inter-program relationships. Thus, the results can be used by distinct audiences including individual scholars, research groups, institutions, research funding organizations, among others.

Individual Scholars

The authors in [47] focus on trend analysis of publication topics using the social network metrics of authors (Ph.Ds. in Computer Science registered in Lattes platform) based on the co-authorship network. Authors developed an approach to enhance the prediction of trend topics in the Computer Science domain in contrast with approaches based on time series. In [48], authors address the question of measuring tie strength in co-authorship social networks and propose a new metric called *tierness*, that is simple to calculate and better differentiates the degrees of strength. The results were good compared to the existing metrics considering three real social networks built from publications collected from digital libraries on Computer Science, Medicine, and Physics.

The authors in [49] worked with individual scholars and research groups characterizing the structural properties of the scientific collaboration network in the area of Computer Science. Authors considered the global network formed by DBLP individuals with 750 thousand authors (collected in June 2009) and over 1.3 million publications, associated with the Brazilian network formed by individuals affiliated with Brazilian institutions (about 1,600 authors). They established a direct comparison between these two networks, ranking individuals within a group in the network using solely their relationships as opposed to ranking all individuals. The proposed group-based metric assigns the importance to an individual proportional to the intensity of its relationship to the outside of the group.

Research Groups

The authors in [46] present statistical analysis comparing the top 25 Brazilian Computer Science graduate programs to understand their strengths and weaknesses. Authors compare the number of faculty members, the number of publications of each researcher (classifying journals and in proceedings), and CAPES graduate program ranking from 3 to 7. This work does not comprehend the analysis of a particular researcher but focuses on group analysis. The authors in [50] aimed to help improve manual research assessment and automatic researchers ranking using a statistical approach. The study focused on the 406 top researchers from Brazilian universities according to the CNPq five ranks (1A, 1B, 1C, 1D, and 2) grouped by computer science research area and H-index ranks.

The authors in [51] investigated the Brazilian Symposium of Database (SBBD) co-authorship network built from bibliographic data of 30 editions (1986 to 2015). The analysis includes several network metrics as the progress of the most engaged authors, the number of distinct authors, institutions, published papers, and the evolution of the most frequent terms presented in the paper titles, as well as the

influence, density, and impact of the prominent authors. This approach does not comprehend the analysis of a particular researcher focusing instead on evaluating statistical averages and ranges.

The authors in [52] used the social network defined by article authors published in the Brazilian Symposium on Computer Networks and Distributed Systems (SBRC) from bibliographic data of 30 editions (1983-2012). Authors used temporal analysis of the network evolution to investigate the number of communities and their inter-relation through time (also considering geographic distribution), the importance of nodes, network homophily, their degree distribution, and correlations.

The authors in [53] investigated the properties of the social network defined by researchers that have served as PC members in the Brazilian Computer Science conferences. This community is composed of non-Brazilian and Brazilian members, who tend to be senior researchers. Like the two previous papers, this doesn't comprehend the analysis of a particular researcher focusing on evaluating statistical averages and ranges.

The authors in [54] investigated whether research articles produced through international collaboration are more novel or only highly cited. Authors failed to show that international collaboration tends to produce more novel articles. The explanations of growth in international collaboration posit a social dynamic of preferential attachment based upon reputation.

Geographic Coverage and Data Source

The geographic coverage of the scientific social network of the related work consider different data sources, but most of them counts on Brazilian data: (1) in [46] the authors are from the top 25 Brazilian computer science graduate programs; (2) in [50] the social network is formed by the top Computer Science researchers of the Brazilian universities; (3) in [51] the authors are from the SBBD; (4) in [47] the authors network is formed by the Ph.Ds. in computer science registered in Latex platform; (5) in [52] the social network is defined by authors that published in the SBRC from 1983 to 2012; (6) in [53] the social network is formed by senior researchers acting as PC members in the Brazilian Computer Science conferences including Brazilian and non-Brazilian members; (7) in [49] the global network is formed by DBLP individuals affiliated with Brazilian institutions (about 1600 authors). The authors in [50, 51] state that although the profile analysis used national data the approach may be used by other countries.

In [48] authors are from three real social networks built from publications collected from digital libraries on Computer Science using articles and in proceedings in the DBLP, medicine with a US national library of the Medicine National Institute of Health that comprises biomedical publications - PubMed (publications from the top-20 journals classified by h-index), and physics with American Physical Society (sample dataset with its journal publications). In [54] authors treat specifically international collaboration using data from Web of Science and Scopus in 2005.

In this work, we used members of five Brazilian Computer Science graduate programs to validate the scientific collaboration network analysis involving publication data of authors and co-authors available on the DBLP library, resulting in 7,368 total authors in 2019 and 8,286 in 2021. The data from the graduate program members are collected from the university site. Thus, the authors from the programs are

mostly from Brazil but co-authors from the world. As future work, the database in SCI-synergy can be extended to include the 88 Computer Science graduate programs in Brazil.

Adopted Metrics, Scope of the Analysis and Implementation

Regarding the adopted metrics, all works used the researchers' volume of publication considering authors, but [50, 49] didn't use co-authoring. In this work, we calculate how many co-authors one author has worked with and how many times this collaboration occurred. In [48] authors apply the "tiness" metric to compute the strength of relationships between a pair of authors to identify when a tie is weak or strong. In [47] social network metrics of Ph.Ds. authors in Computer Science are computed based on the co-authorship network. We also applied social network metrics such as *average degree*, *connected components*, *betweenness* and *closeness centralities*. The papers [50, 51, 46] dealt with venue's quality using the Brazilian CAPES Qualis ranking.

Regarding the scope of analysis, the works [47, 48, 52, 53, 49] have applied network properties implementing them. Collaboration patterns were considered in [46, 51, 52, 53, 49, 54]. Specially small world and link density collaboration patterns were applied in [51, 53]. Temporal evolution is taken into account in [46, 50, 51, 47, 52, 54], but mainly manipulated manually. In this work, we made use of the absolute frequency of interaction, but we stand out by considering the elapsed time between the co-authorship. Using SCI-synergy it is possible year-round queries, where a researcher might query his/her network or the graduate program network considering publications within a specific period (e.g. the last 3 years). Note that our work is the only one that focuses analysis on intra- and inter-program collaboration patterns.

Considering implementation aspects, there is no solution implemented with code available in any of the presented related work. The SCI-synergy online artifact is implemented with the code available in the GitLab as presented in the Technologies Summary section.

Note by the summarized aspects listed in Table 9, that our work is the only one with an implementation available with SCI-synergy that presents an intra- and inter-program analysis using social network metrics.

Conclusion

This work presents a scientific collaboration network analysis of five Brazilian Computer Science graduate programs using social network metrics and the SCI-synergy artifact. The analysis focuses on the researchers' collaboration involving publication data available on the DBLP to understand patterns of intra- and inter-program relationships considering two database updates of 2019-12-27 and 2021-02-03. Three research questions posed to be investigated were answered through the analysis of scientific co-authorship applying social network metrics – *average degree*, *connected components*, *betweenness centrality*, and *closeness centrality*.

The database update comparison allows many interesting results as the number of members in the graduate programs have a little increased from 179 to 194:

- This increase resulted in changes in the number of co-authors, co-authorship relations, total publications, and consequently decreased the *average degree* of the programs (Tables 1 and 2). The highest increase in the number of researchers was in UFMG with six or 10% of the amount in 2019, and five new researchers in UnB and UFRN. However, the number of researchers decreased by one in USP (2% of the amount in 2019) and kept the same in UFAM.
- The *betweenness centrality* shows a high concentration of UFMG researchers acting as “bridge” in the collaboration network (60% - Table 3) that decreased to 40% in 2021.
- The *closeness centrality* shows that UFMG researchers can influence the entire network quicker as they boost the flow of knowledge (90% in 2019 and 60% in 2021 - Table 4).
- The internationalization relative score shows a great variation among the graduate programs’ researchers, where not always the highest CNPq fellow scholarship presents the biggest international collaboration network (Table 5).
- The intra-program analysis presents UFMG and UFAM with the highest relative score of collaboration in 2021 with 57 (3,498/61) and 21 (764/36) collaboration per researcher, respectively. The inter-program analysis shows that UFMG and USP are connected to all other programs (Table 6a and 6b). The *connected components* shows only one big group of researchers that present a uniform participation distribution in 2019, but in 2021 this scenario changed a lot according to (Table 7, Figures 15 and 16). This result demands further investigation, but a first guess relates to the pandemic situation over 2020.

In future work, the SCI-synergy database could be extended to include the 88 Computer Science graduate programs in Brazil. Affiliation attributes would be introduced in the database to allow institutional analysis and internationalization aspects of co-authorship. Also, different data sources can be explored like Web of Science and Scopus to include evaluation of other knowledge domains. Disambiguation techniques have to be improved to explore authors’ correspondence. Finally, additional network metrics, such as degree centrality, Eigenvector centrality, Katz centrality, transitivity, reciprocity, and similarity, can be used to compute different collaboration aspects.

List of abbreviations

CAPES Brazilian Coordination for the Improvement of Higher Education Personnel. 1, 6, 9, 11–14, 16, 18, 33
CNPq Brazilian National Council for Scientific and Technological Development. 10, 11, 14, 16, 19, 20, 31, 32

DBLP Digital Bibliography & Library Project. 1, 2, 5–8, 10

DOM Document Object Model. 8

DSR Design Science Research. 3, 6

JSON JavaScript Object Notation. 7, 8

NoSQL Not only Structured Query Language. 6–8

SAX Simple API for XML. 8

TF-IDF term frequency-inverse document frequency. 5

UFAM Federal University of Amazonas. 1, 3, 6, 8–15, 19, 26, 31–33

UFMG Federal University of Minas Gerais. 1, 2, 6, 8–14, 19, 25, 31–33

UFRN Federal University of Rio Grande do Norte. 1–3, 6, 8–15, 19, 27, 31–33

UnB University of Brasília. 1, 3, 6, 8–12, 14, 15, 19, 27, 31–33

USP State University of São Paulo. 1, 2, 6, 8–15, 19, 26, 31–33

XML eXtensible Markup Language. 6–8

Availability of data and materials

SCI-synergy is an open source project available in the GitLab InfoKnow research group project repository (<https://gitlab.com/InfoKnow/SocialNetwork/aureliocosta-sci-synergy>). InfoKnow research group is registered at the Directory of Research Groups in Brazil administered by the Brazilian National Council for Scientific and Technological Development (CNPq) (<http://dgp.cnpq.br/dgp/espelhogrupo/34202>). SCI-synergy code is free to copy, distribute, use, modify, transform, build upon, and produce derived works from our data as long as you attribute any public use of the data, or works produced from the data, in the manner specified in the license under the Creative Commons Attribution 4.0 International License (CC-BY 4.0). The full CC-BY 4.0 license text for the terms is available in <https://creativecommons.org/licenses/by/4.0/>.

Competing interests

The authors declare that they have no competing interests.

Funding

Not applicable.

Author's contributions

ARC is the main author of the research presenting the results of his Computer Science Master dissertation. CGR was his supervisor, which analyzed the research proposal, supervised the development of the project, and wrote most of the sections of the manuscript. VTN contributed to discussions and insights from the data analysis and on writing parts of the manuscript. All authors read and approved the final manuscript.

Acknowledgements

The authors thank the support provided by the involved universities. Prof. C. G. Ralha thanks the support received from the Brazilian National Council for Scientific and Technological Development (CNPq) under grant number 311301/2018-5.

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References

- Zhang, C., Bu, Y., Ding, Y., Xu, J.: Understanding scientific collaboration: Homophily, transitivity, and preferential attachment. *J. of the Association for Information Science and Technology* **69**(1), 72–86 (2018)
- Coxon, A.P.M.: Perspectives on social network. In: Holland, P.W., Leinhardt, S. (eds.) *Perspectives on Social Network Research*, pp. 489–500. Academic Press, Oxford (1979). Chap. 23
- Katz, J.S., Martin, B.R.: What is research collaboration? *Research Policy* **26**(1), 1–18 (1997)
- Newman, M.E.J.: Coauthorship networks and patterns of scientific collaboration. *Proceedings of the national academy of sciences of the United States of America* **101**(suppl 1), 5200–5205 (2004)
- Cronin, B.: *The Hand of Science: Academic Writing and Its Rewards*. Scarecrow Press, Lanham, MD, USA (2005)
- Meyer, M., Bhattacharya, S.: Commonalities and differences between scholarly and technical collaboration. *Scientometrics* **61**(3), 443–456 (2004)
- Garg, K.C., Padhi, P.: A study of collaboration in laser science and technology. *Scientometrics* **51**(2), 415–427 (2001)
- Glänzel, W.: National characteristics in international scientific co-authorship relations. *Scientometrics* **51**(1), 69–115 (2001)
- Tomizawa, H., Shirabe, M.: Likelihood of overseas access to international co-authorships. *Scientometrics* **53**(1), 113–121 (2002)
- Yoshikane, F., Kageura, K.: Comparative analysis of coauthorship networks of different domains: The growth and change of networks. *Scientometrics* **60**(3), 435–446 (2004)
- Alonso-Arroyo, A., Pulgarín, A., Gil-Leiva, I.: Estudio cuantitativo de la colaboración científica en la universidad politécnica de valencia (españa). *Information Research* **11**(1) (2005)
- Kim, K.-W.: Measuring international research collaboration of peripheral countries: Taking the context into consideration. *Scientometrics* **66**(2), 231–240 (2006)
- Glänzel, W.: Coauthorship patterns and trends in the sciences (1980-1998): A bibliometric study with implications for database indexing and search strategies. *Library trends* **50**(3), 461–475 (2002)
- Chesbrough, H., Vanhaverbeke, W., West, J.: *Open Innovation: Researching a New Paradigm*. Oxford University Press, Oxford, UK (2006)
- Park, J.-H., Nam, E.: Intra- and inter-institutional collaborative pairing trends of IIS field in south Korea. *Libri* **66**(2), 125–136 (2016). doi:10.1515/libri-2015-0096
- Savić, M., Ivanović, M., B., D.S.: Analysis of intra-institutional research collaboration: a case of a Serbian faculty of sciences. *Scientometrics* **110**(1), 195–216 (2017). doi:10.1007/s11192-016-2167-z
- Laender, A.H.F., de Lucena, C.J.P., Maldonado, J.C., de Souza e Silva, E., Ziviani, N.: Assessing the research and education quality of the top Brazilian computer science graduate programs. *ACM SIGCSE Bulletin* **40**(2), 135–145 (2008). Invited Report
- Arruda, D., Bezerra, F., Neris, V.A., Toro, P.R.D., Wainera, J.: Brazilian computer science research: Gender and regional distributions. *Scientometrics* **79**, 651–665 (2009). doi:10.1007/s11192-007-1944-0
- Digiampietri, L.A., Mena-Chalco, J.P., de Melo, P.O.S.V., Malheiro, A.P.R., Meira, D.N.O., Franco, L.F., Oliveira, L.B.: Brax-ray: An x-ray of the Brazilian computer science graduate programs. *Plos One* **9**(4), 1–12 (2014). doi:10.1371/journal.pone.0094541

20. Linden, R., Barbosa, L.F., Digiampietri, L.A.: "brazilian style science"—an analysis of the difference between brazilian and international computer science departments and graduate programs using social networks analysis and bibliometrics. *Social Network Analysis and Mining* **44**(7) (2017). doi:10.1007/s13278-017-0463-0
21. Lopes, G.R., da Silva, R., Moro, M.M., de Oliveira, J.P.M.: Scientific collaboration in research networks: A quantification method by using gini coefficient. *Int. J. Comput. Sci. Appl.* **9**(2), 15–31 (2012)
22. Costa, A.R., Ralha, C.G.: Analysis of scientific collaboration network as a management tool for graduate programs. In: *Proceedings of the Annual Conference on Brazilian Symposium on Information Systems: A Computer Socio-Technical Perspective - Volume 1*. SBSI 2015, pp. 275–282. Brazilian Computer Society, Porto Alegre, BRA (2015)
23. Costa, A.R., Ralha, C.G.: Análise de Rede de Colaboração Científica Como Ferramenta na Gestão de Programas de Pós-graduação vol. *Princípios e Aplicações da Computação no Brasil 2*, pp. 96–108. Atena Editora, Ponta Grossa, Paraná, Brazil (2019). doi:10.22533/at.ed.48319160110. <https://www.atenaeditora.com.br/post-artigo/4924> (visited 2019-04-11)
24. Franceschet, M.: Collaboration in computer science: A network science approach. *Journal of the Association for Information Science & Technology* **62**(10), 1992–2012 (2011)
25. Jiang, J., Shi, P., An, B., Yu, J., Wang, C.: Measuring the social influences of scientist groups based on multiple types of collaboration relations. *Information Processing & Management* **53**(1), 1–20 (2017). doi:10.1016/j.ipm.2016.06.003
26. Yu, S., Bedru, H.D., Lee, I., Xia, F.: Science of scientific team science: A survey. *Computer Science Review* **31**, 72–83 (2019). doi:10.1016/j.cosrev.2018.12.001
27. Ley, M.: The DBLP computer science bibliography: Evolution, research issues, perspectives. In: Laender, A.H.F., Oliveira, A.L. (eds.) *International Symposium on String Processing and Information Retrieval (SPIRE)*. Lecture Notes in Computer Science, vol. 2476, pp. 1–10. Lisbon, Portugal (2002). doi:10.1007/3-540-45735-6_1. Springer, Berlin, Heidelberg
28. Hevner, A.R., March, S.T., Park, J., Ram, S.: Design science in information systems research. *MIS Q.* **28**(1), 75–105 (2004)
29. March, S.T., Storey, V.C.: Design science in the information systems discipline: An introduction to the special issue on design science research. *MIS Q.* **32**(4), 725–730 (2008)
30. Weber, S.: Design science research: Paradigm or approach? In: *AMCIS 2010 Proceedings* (2010)
31. Simon, H.A.: *The Sciences of the Artificial*. MIT press, Cambridge, MA (1996)
32. Hevner, A., Chatterjee, S.: *Design Research in Information Systems: Theory and Practice*, 1st edn. Springer, New York, NY, USA (2010)
33. Newman, M.: *Networks: An Introduction*. Oxford University Press, Oxford, New York (2010)
34. Bonacich, P.: Power and centrality: A family of measures. *American Journal of Sociology* **92**(5), 1170–1182 (1987)
35. Kang, I., Na, S., Lee, S., Jung, H., Kim, P., Sung, W., Lee, J.: On co-authorship for author disambiguation. *Inf. Process. Manag.* **45**(1), 84–97 (2009). doi:10.1016/j.ipm.2008.06.006
36. Paul, P.P., Sultana, M., Matei, S.A., Gavriloa, M.L.: Authorship disambiguation in a collaborative editing environment. *Comput. Secur.* **77**, 675–693 (2018). doi:10.1016/j.cose.2018.01.010
37. Ferreira, A.A., Gonçalves, M.A., Laender, A.H.F.: Automatic Disambiguation of Author Names in Bibliographic Repositories. Morgan & Claypool, San Rafael, CA, USA (2020). doi:10.2200/S01011ED1V01Y202005ICR070
38. Tang, L., Walsh, J.: Bibliometric fingerprints: name disambiguation based on approximate structure equivalence of cognitive maps. *Scientometrics* **84**(3), 763–784 (2010)
39. Cohen, W., Ravikumar, P., Fienberg, S.: A comparison of string metrics for matching names and records. In: *KDD Workshop on Data Cleaning and Object Consolidation*, pp. 73–78 (2003)
40. Navarro, G.: A guided tour to approximate string matching. *ACM computing surveys (CSUR)* **33**(1), 31–88 (2001)
41. Brandes, U., Pich, C.: Centrality estimation in large networks. *International Journal of Bifurcation and Chaos* **17**(07), 2303–2318 (2007). doi:10.1142/S0218127407018403
42. Bastian, M., Heymann, S., Jacomy, M.: Gephi: an open source software for exploring and manipulating networks. In: *Proceedings of the 3rd International AAAI Conference on Weblogs and Social Media (ICWSM)* (2009)
43. Holzschuher, F., Peinl, R.: Performance of graph query languages: comparison of cypher, gremlin and native access in neo4j. In: *Proceedings of the Joint EDBT/ICDT 2013 Workshops*, pp. 195–204 (2013). ACM
44. Hagberg, A., Swart, P., S. Chult, D.: Exploring network structure, dynamics, and function using networkx. In: *Proceedings of the 7th Python in Science Conferences (SciPy 2008)*, pp. 11–16 (2008)
45. Milgram, S.: The small world problem. *Psychology today* **2**(1), 60–67 (1967)
46. Silva, T.H.P., Laender, A.H.F., Jr., C.A.D., da Silva, A.P.C., Moro, M.M.: A profile analysis of the top brazilian computer science graduate programs. *Scientometrics* **113**(1), 237–255 (2017)
47. Trucolo, C.C., Digiampietri, L.A.: Improving trend analysis using social network features. *J. Braz. Comp. Soc.* **23**(1), 8 (2017)
48. Brandão, M.A., Moro, M.M.: The strength of co-authorship ties through different topological properties. *J. Braz. Comp. Soc.* **23**(1), 5 (2017)
49. Freire, V.P., Figueiredo, D.R.: Ranking in collaboration networks using a group based metric. *J. Braz. Comp. Soc.* **17**(4), 255–266 (2011)
50. Lima, H., Silva, T.H.P., Moro, M.M., Santos, R.L.T., Meira, W., Laender, A.H.F.: Assessing the profile of top brazilian computer science researchers. *Scientometrics* **103**(3), 879–896 (2015)
51. Lima, L.H.C., Penha, G., de A. Rocha, L.M., Moro, M.M., da Silva, A.P.C., Laender, A.H.F., de Oliveira, J.P.M.: The collaboration network of the brazilian symposium on databases-30 editions of history. *J. Braz. Comp. Soc.* **23**(1), 10 (2017)

52. Maia, G., de Melo, P.O.S.V., Guidoni, D.L., Souza, F.S.H., Silva, T.H.P., Almeida, J.M., Loureiro, A.A.F.: On the analysis of the collaboration network of the brazilian symposium on computer networks and distributed systems. *J. Braz. Comp. Soc.* **19**(3), 361 (2013)
53. Bazzan, A.L.C., Argenta, V.F.: Network of collaboration among PC members of brazilian computer science conferences. *J. Braz. Comp. Soc.* **17**(2), 133–139 (2011)
54. Wagner, C.S., Whetsell, T.A., Mukherjee, S.: International research collaboration: Novelty, conventionality, and a typicality in knowledge recombination. *Research Policy* **48**(5), 1260–1270 (2019)

Figures

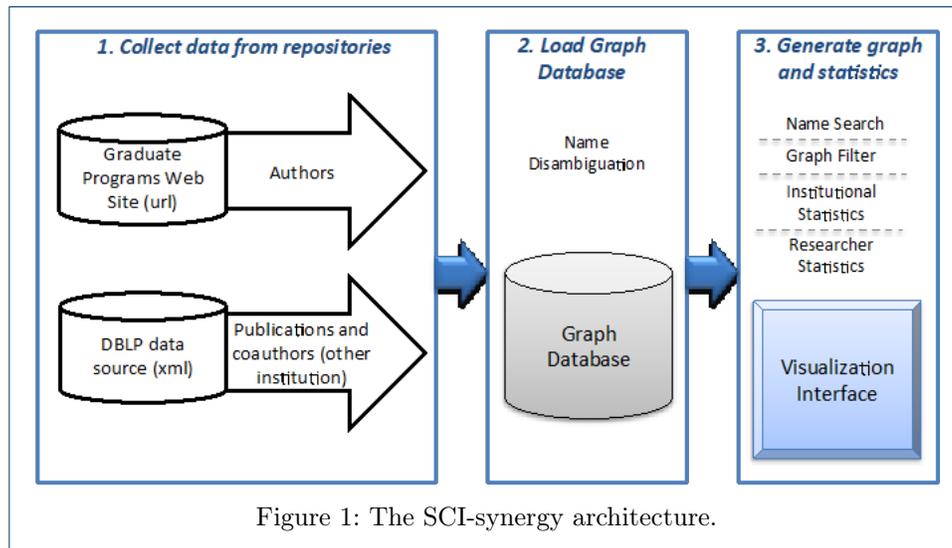


Figure 1: The SCI-synergy architecture.

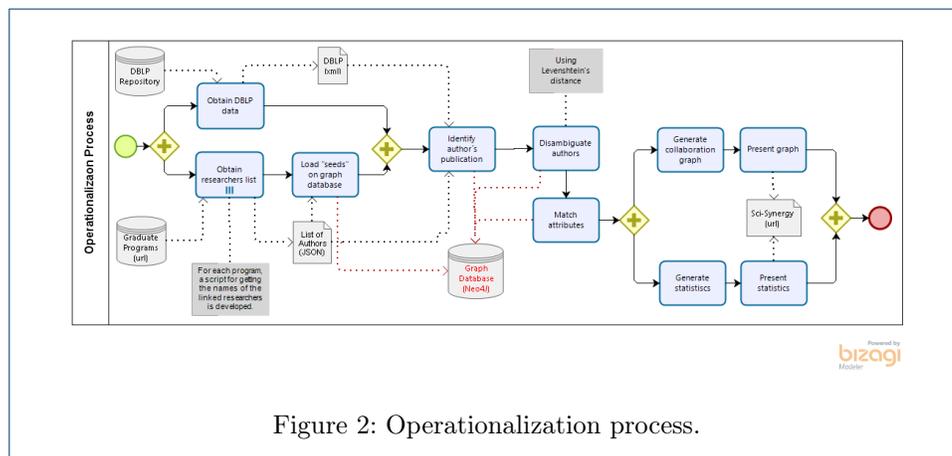


Figure 2: Operationalization process.

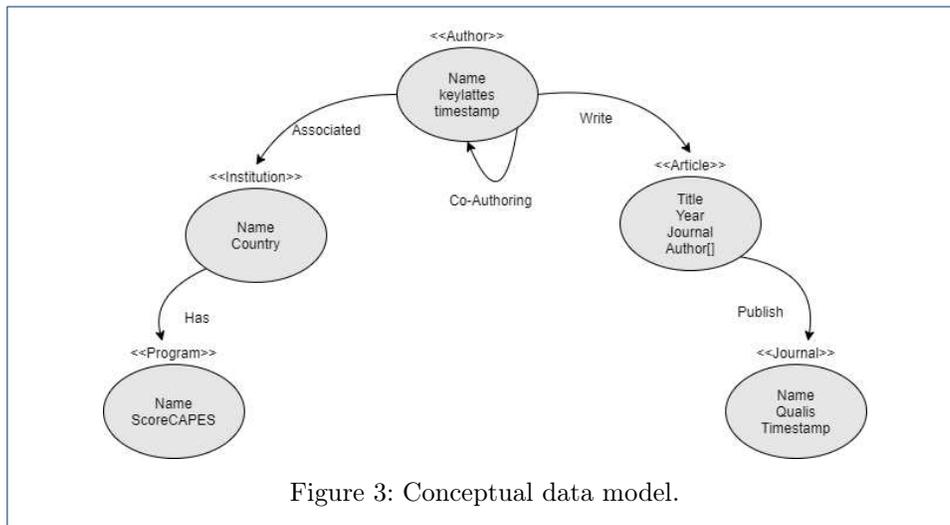


Figure 3: Conceptual data model.

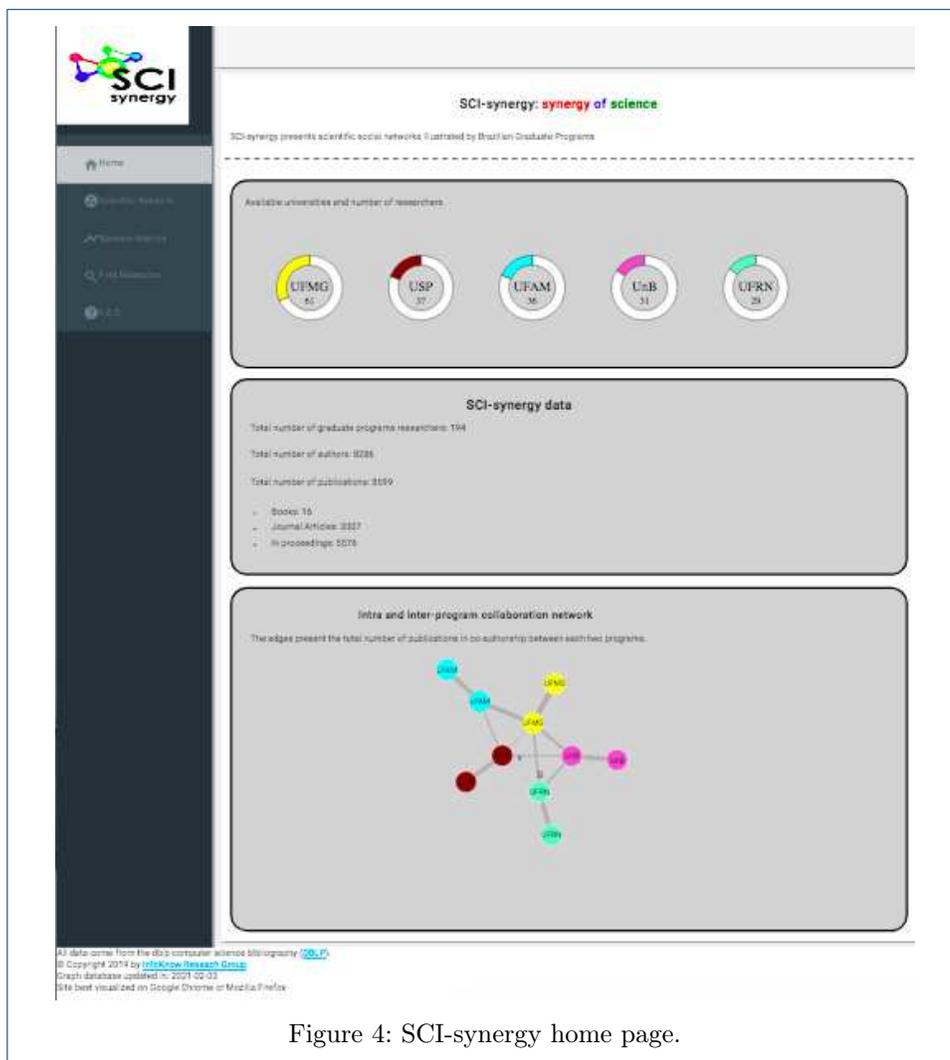


Figure 4: SCI-synergy home page.

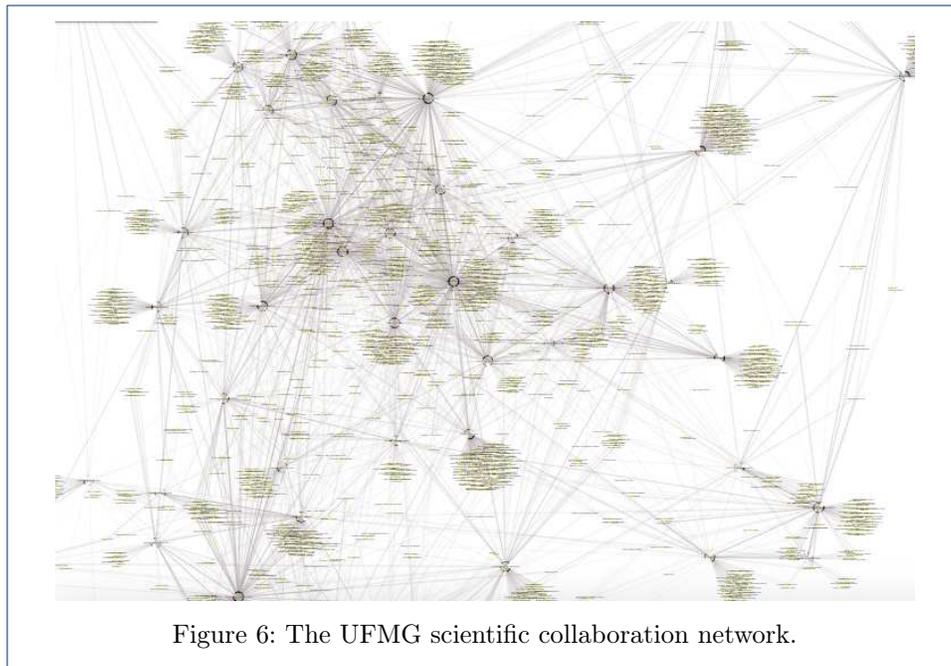
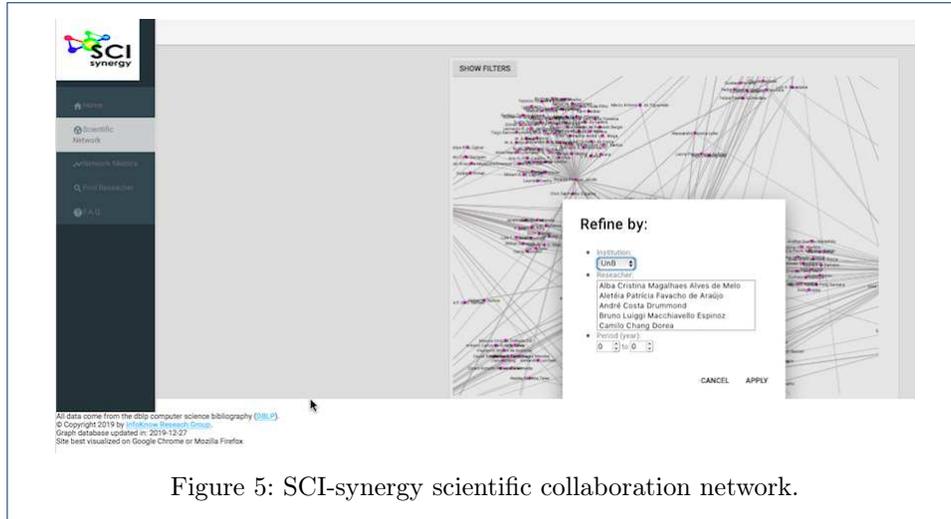


Figure 6: The UFMG scientific collaboration network.

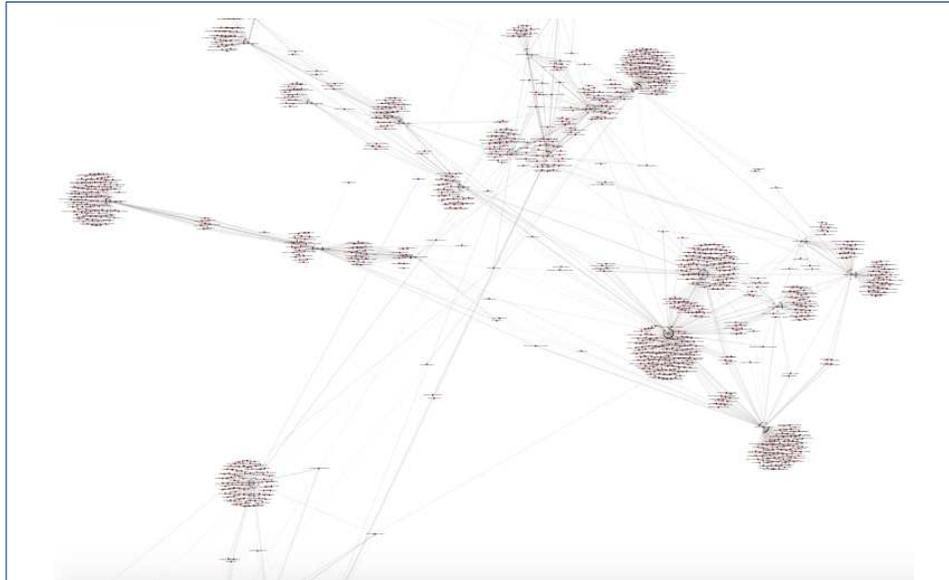


Figure 7: The USP scientific collaboration network.

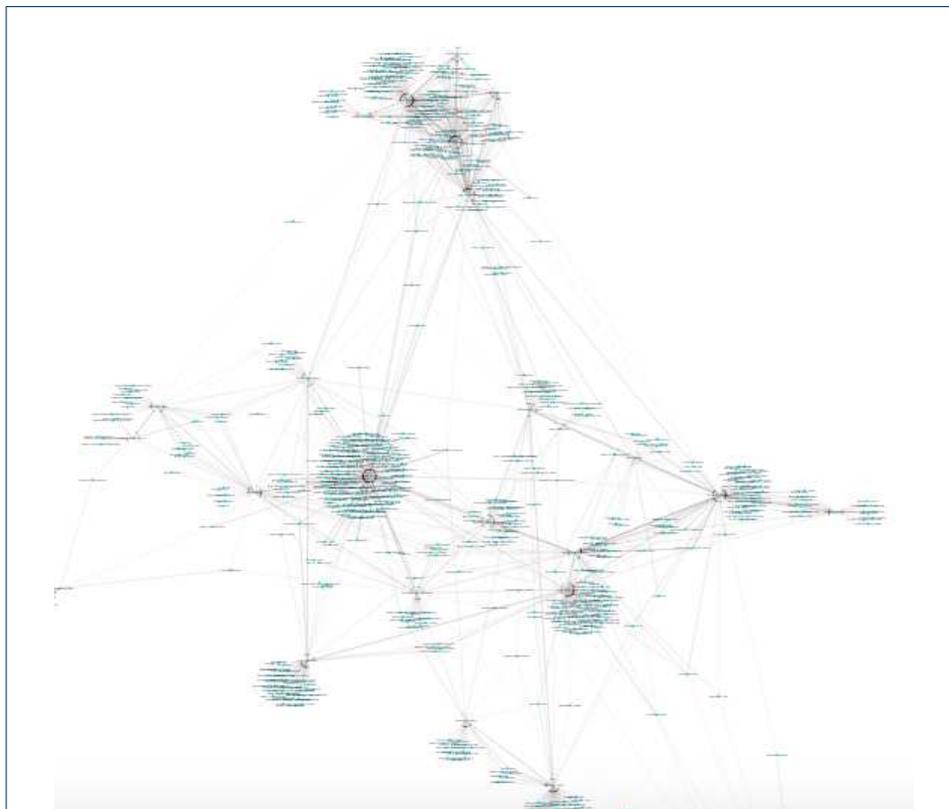


Figure 8: The UFAM scientific collaboration network.

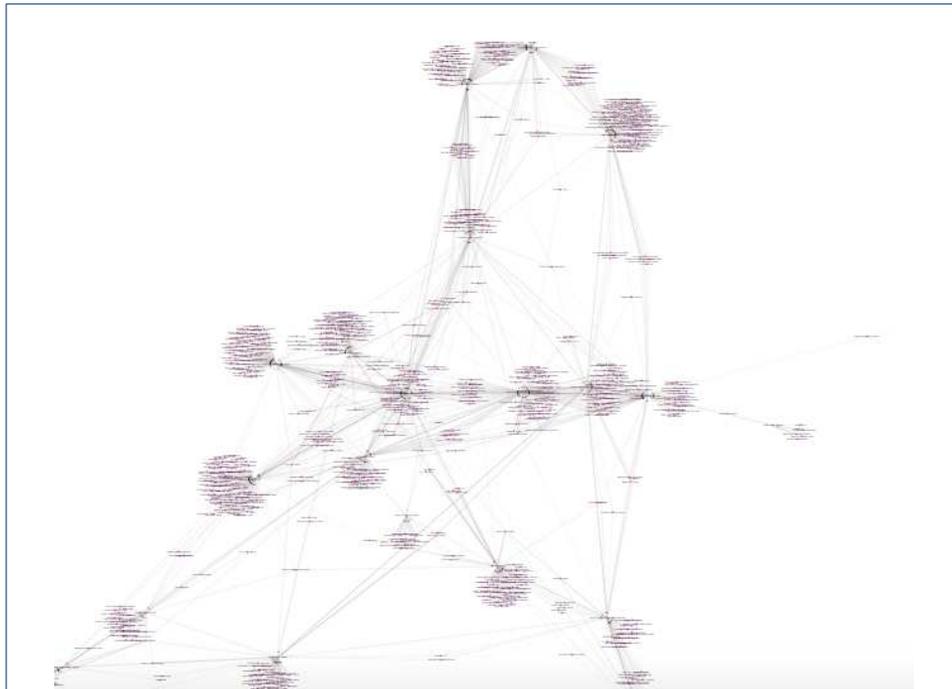


Figure 9: The UnB scientific collaboration network.

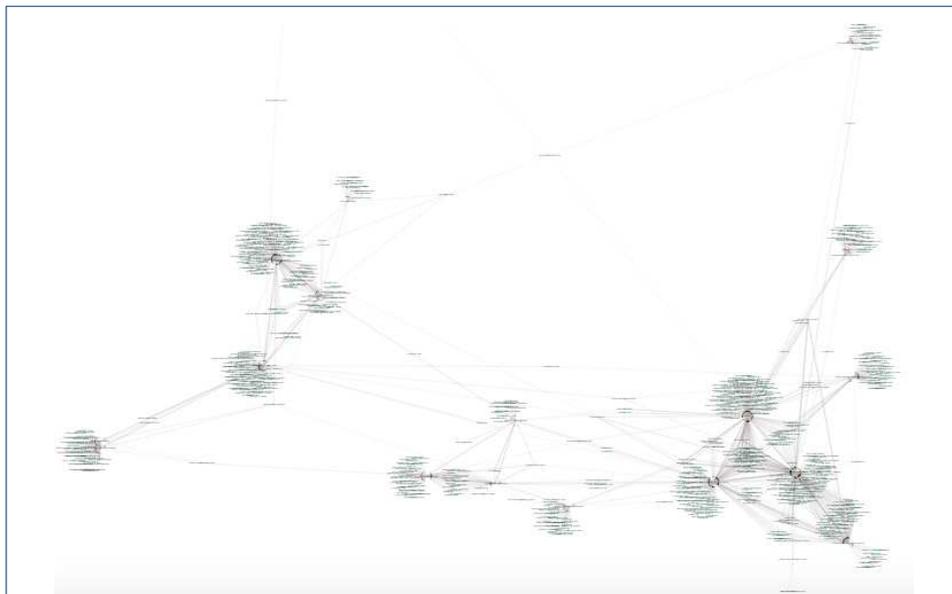
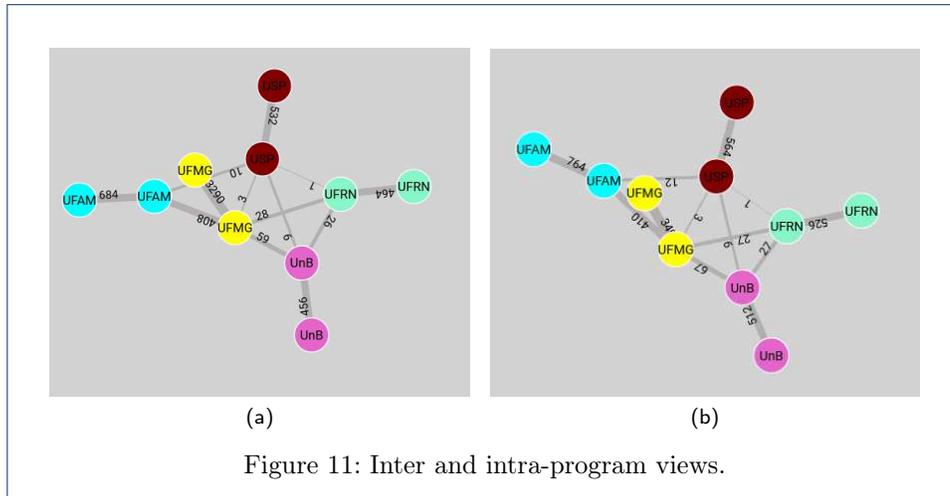


Figure 10: The UFRN scientific collaboration network.



(a) (b)
Figure 11: Inter and intra-program views.

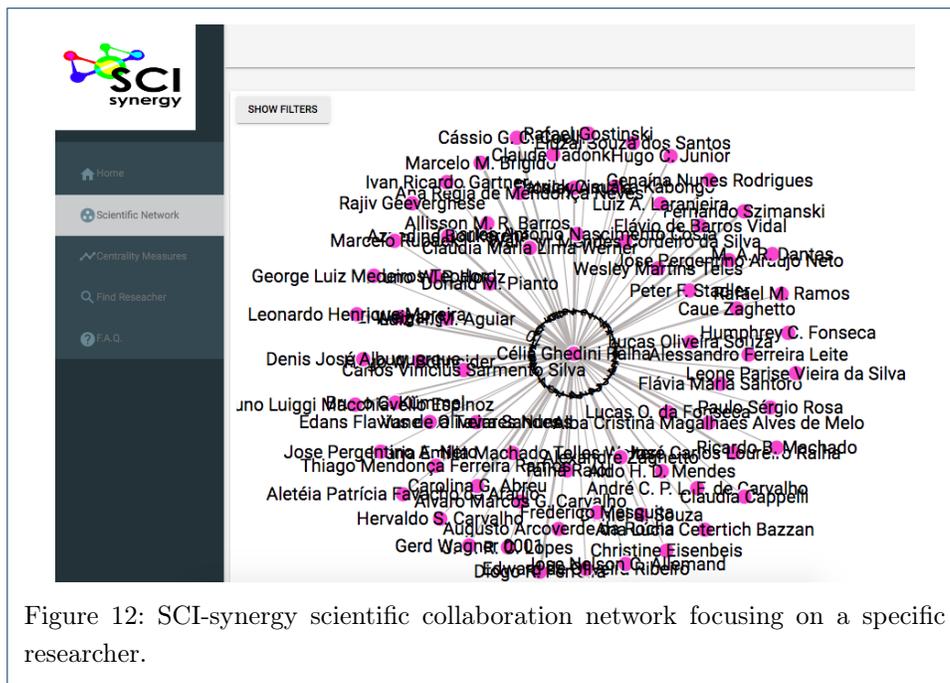


Figure 12: SCI-synergy scientific collaboration network focusing on a specific researcher.

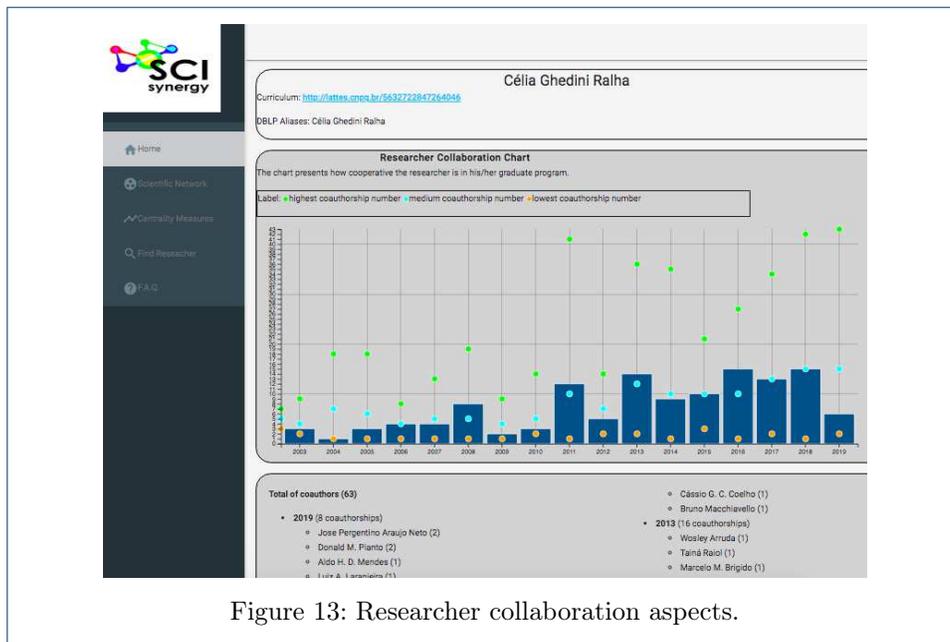


Figure 13: Researcher collaboration aspects.

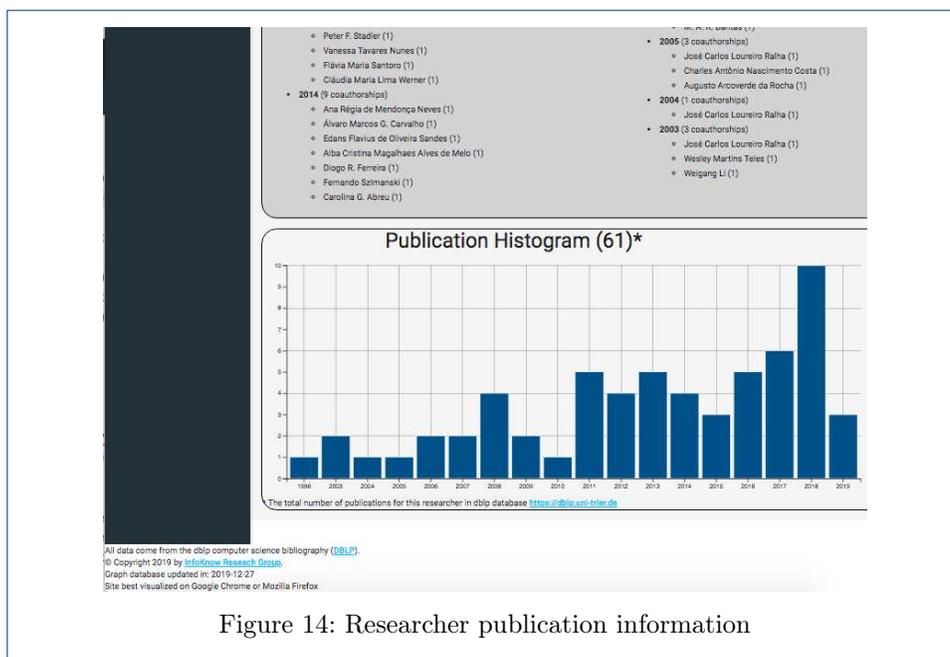


Figure 14: Researcher publication information

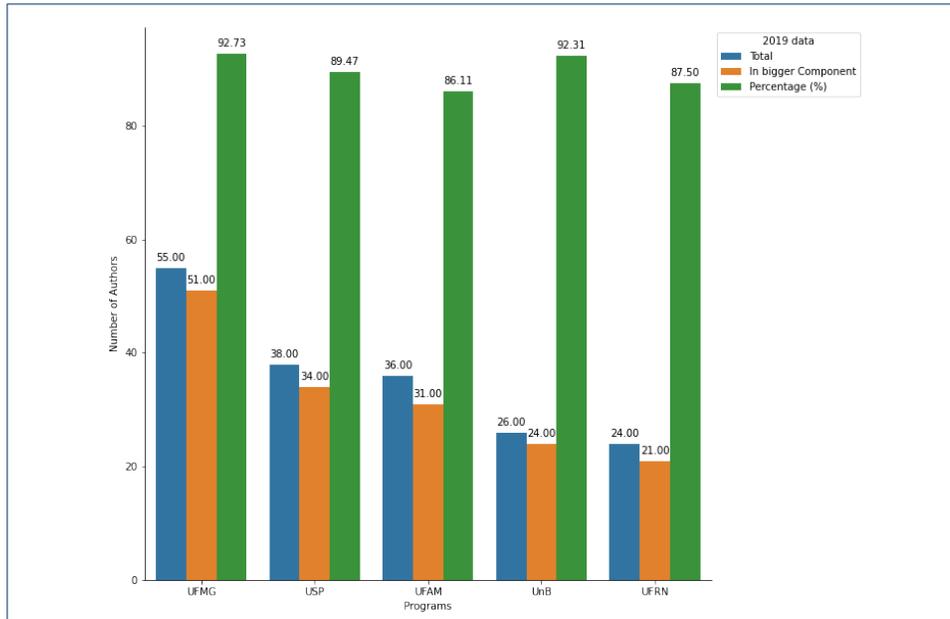


Figure 15: Authors' participation of the bigger component (2019).

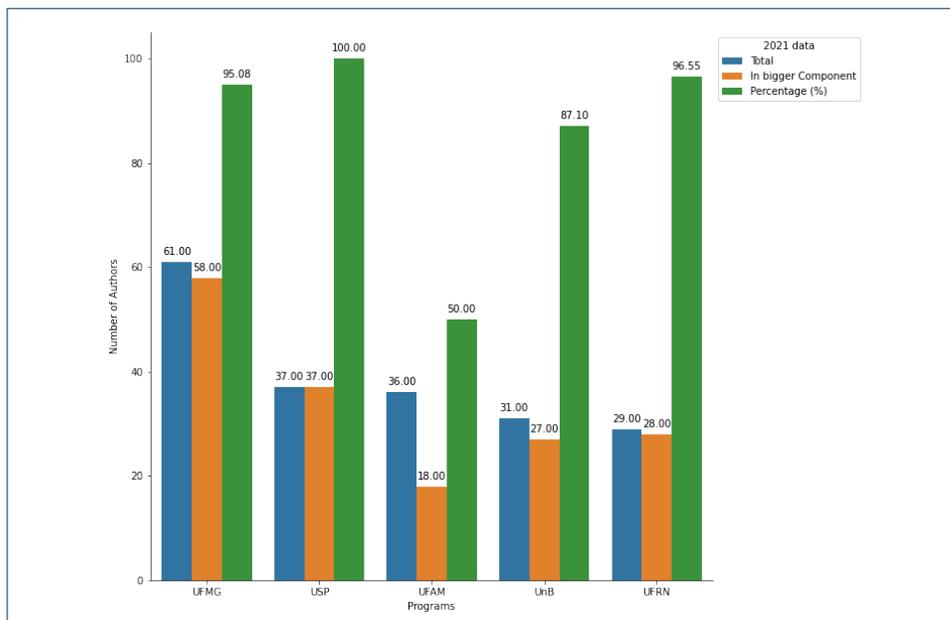


Figure 16: Authors' participation of the bigger component (2021).

Tables

Table 1: The graduate programs total amounts considering 2019 database update.

Institution Name	Number Researchers	Number Co-authors	Co-authorship Relations	Publication Period	Total Publications	Average Degree
UFMG	55	3,110	14,515	1981-2019	3,157	4.58
USP	38	1,434	4,068	1980-2019	1,624	2.76
UFAM	36	895	3,526	1995-2019	819	3.78
UnB	26	1,097	3,421	1992-2019	1,016	3.04
UFRN	24	1,081	4,042	1994-2019	983	3.65

Table 2: The graduate programs total amounts considering 2021 database update.

Institution Name	Number Researchers	Number Co-authors	Co-authorship Relations	Total Publications	Average Degree
UFMG	61	3,557	12,643	5,368	3.49
USP	37	1,654	4,144	2,141	2.45
UFAM	36	621	1,761	698	2.63
UnB	31	1,590	3,762	1,601	2.32
UFRN	29	1,310	3,792	1,578	2.83

Table 3: The ten highest *betweenness centrality* scores.

2019-12-27				2021-02-03			
Researcher	Graduate Program	CNPq Fellow	Score	Researcher	Graduate Program	CNPq Fellow	Score
Name1	UFMG	PQ 1A	2,893,667	Name3	UFMG	PQ 1B	64,562.23
Name2	UFMG	PQ 1C	2,596,507	Name9	UFAM	PQ 2	47,834.69
Name3	UFMG	PQ 1B	2,507,440	Name2	UFMG	PQ 1C	47,403.24
Name4	PUC-Rio	PQ 1A	1,593,966	Name11	UFMG	PQ 2	44,407.80
Name5	USP	PQ 1D	1,579,236	Name15	UFPA	PQ 1C	39,396.06
Name6	UFMG	PQ 1B	1,404,162	Name16	UFAM	—	39,344.51
Name7	UFMG	PQ 2	1,354,982	Name17	PUC-Rio	PQ 1B	31,415.99
Name8	UFMG	PQ 1A	1,308,625	Name18	UFRJ	PQ 1D	30,324.27
Name9	UFAM	PQ 2	1,191,750	Name19	Unicamp	PQ 1A	28,818.15
Name10	University of Ottawa, CA	—	1,190,203	Name20	UFMG	PQ 1D	28,590.83

Table 4: The ten highest *closeness centrality* scores.

2019-12-27				2021-02-03			
Researcher	Graduate Program	CNPq Fellow	Score	Researcher	Graduate Program	CNPq Fellow	Score
Name2	UFMG	PQ 1C	0.3305	Name21	UnB	—	6,748.0
Name3	UFMG	PQ 1B	0.3239	Name22	UFMG	—	5,616.0
Name1	UFMG	PQ 1A	0.3167	Name23	UFMG	PQ 2	5,408.0
Name7	UFMG	PQ 2	0.3123	Name24	UFMG	—	5,341.0
Name4	PUC-Rio	PQ 1A	0.3089	Name25	USP	—	5,085.0
Name11	UFMG	PQ 2	0.3058	Name26	UFMG	—	3,993.0
Name12	UFMG	PQ 1A	0.3044	Name27	UnB	PQ 1D	3,348.0
Name8	UFMG	PQ 1A	0.3023	Name28	UFRN	—	3,092.0
Name13	UFMG	PQ 1B	0.3018	Name1	UFMG	PQ 1A	2,852.0
Name14	UFMG	PQ 1A	0.3017	Name12	UFMG	PQ 1A	2,715.0

Table 5: The intra-, inter-program, national, and international collaborations.

Researcher	Program	CNPq Fellow	Intra-program	Inter-program	National	International	Intl. (%)
Name1	UFMG	PQ 1A	20	4	228	49	16.27
Name2	USP	PQ 1D	7	0	118	84	40.19
Name3	UFAM	PQ 1B	4	14	139	10	5.98
Name4	UnB	PQ 1B	2	0	20	46	67.64
Name5	UFRN	PQ 1D	5	3	183	30	13.57

Table 6: Intra- and inter-program research collaboration network.

(a) 2019 database update.

	UFMG	USP	UFAM	UnB	UFRN
UFMG	3,290	3	408	59	28
USP	3	532	10	9	1
UFAM	408	10	684	-	-
UnB	59	9	-	456	26
UFRN	28	1	-	26	464

(b) 2021 database update.

	UFMG	USP	UFAM	UnB	UFRN
UFMG	3,498	3	410	67	28
USP	3	564	12	9	1
UFAM	410	12	764	-	-
UnB	67	9	-	512	27
UFRN	28	1	-	27	526

Table 7: First ten groups of *connected components* with two database updates.

2019-12-27			2021-02-03		
Identification Component	Total Members	Program Members	Identification Component	Total Members	Program Members
8	6,933	160	0	8,373	168
141	18	1	824	7	1
50	15	1	2853	4	1
158	14	1	714	2	1
176	13	1	2817	1	1
18	10	1	2824	1	1
153	9	1	2816	1	1
128	5	1	2831	1	1
24	1	1	2850	1	1
7	1	1	2825	1	1

Table 8: Overview of scientific collaboration network analysis.

(a) 2019 database update.

Program CAPES	Average Degree	Betweenness Centrality	Closeness Centrality	Intra & Inter Collaboration	Connected Components
UFMG level 7	4.58	60%	90%	3,290 498	51/55 92.73%
USP level 6	2.76	10%	0%	532 23	34/38 89.47%
UFAM level 5	3.78	10%	0%	684 418	31/36 86.11%
UnB level 5	3.04	0%	0%	456 94	24/26 92.31%
UFRN level 5	3.65	0%	0%	464 55	21/24 87.50%

(b) 2021 database update.

Program CAPES	Average Degree	Betweenness Centrality	Closeness Centrality	Intra & Inter Collaboration	Connected Components
UFMG level 7	3.49	40%	60%	3,498 508	58/61 95.08%
USP level 6	2.45	0%	10%	564 25	37/37 100.00%
UFAM level 5	2.63	20%	0%	764 422	18/36 50.00%
UnB level 5	2.32	0%	20%	512 103	27/31 87.10%
UFRN level 5	2.83	0%	10%	526 56	28/29 96.55%

Table 9: This work with SCI-synergy compared to related work.

	[46]	[50]	[51]	[47]	[48]	[52]	[53]	[49]	[54]	SCI-synergy
<i>Focus of the study</i>										
- individual scholars	-	-	-	✓	✓	-	-	✓	-	✓
- research groups	✓	✓	✓	-	-	✓	✓	✓	✓	✓
<i>Geographic Coverage</i>										
- specific country	✓	✓	✓	✓	-	✓	✓	✓	-	✓
- the world	-	-	-	-	✓	-	✓	✓	✓	✓
<i>Data Source</i>										
- DBLP	✓	-	-	-	✓	-	-	✓	-	✓
- other ^a	✓	✓	✓	✓	-	✓	✓	✓	✓	✓
<i>Adopted metrics</i>										
- publication volume	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
- co-authoring counts	✓	-	✓	✓	✓	✓	✓	-	✓	✓
- social network metrics	-	-	-	✓	-	-	-	-	-	✓
<i>Scope of the analysis</i>										
- network properties	-	-	-	✓	✓	✓	✓	✓	-	✓
- collaboration patterns	✓	-	✓	-	-	✓	✓	✓	✓	✓
- temporal evolution	✓	✓	✓	✓	-	✓	-	-	✓	✓
- intra & inter-program	-	-	-	-	-	-	-	-	-	✓
<i>Implementation</i>										
- code & use availability	-	-	-	-	-	-	-	-	-	✓

^a Lattes platform (<http://lattes.cnpq.br>), Journal and Event Management System of the Brazilian Computing Society (<https://jems.sbc.org.br>), graduate programs web sites, etc...

Figures

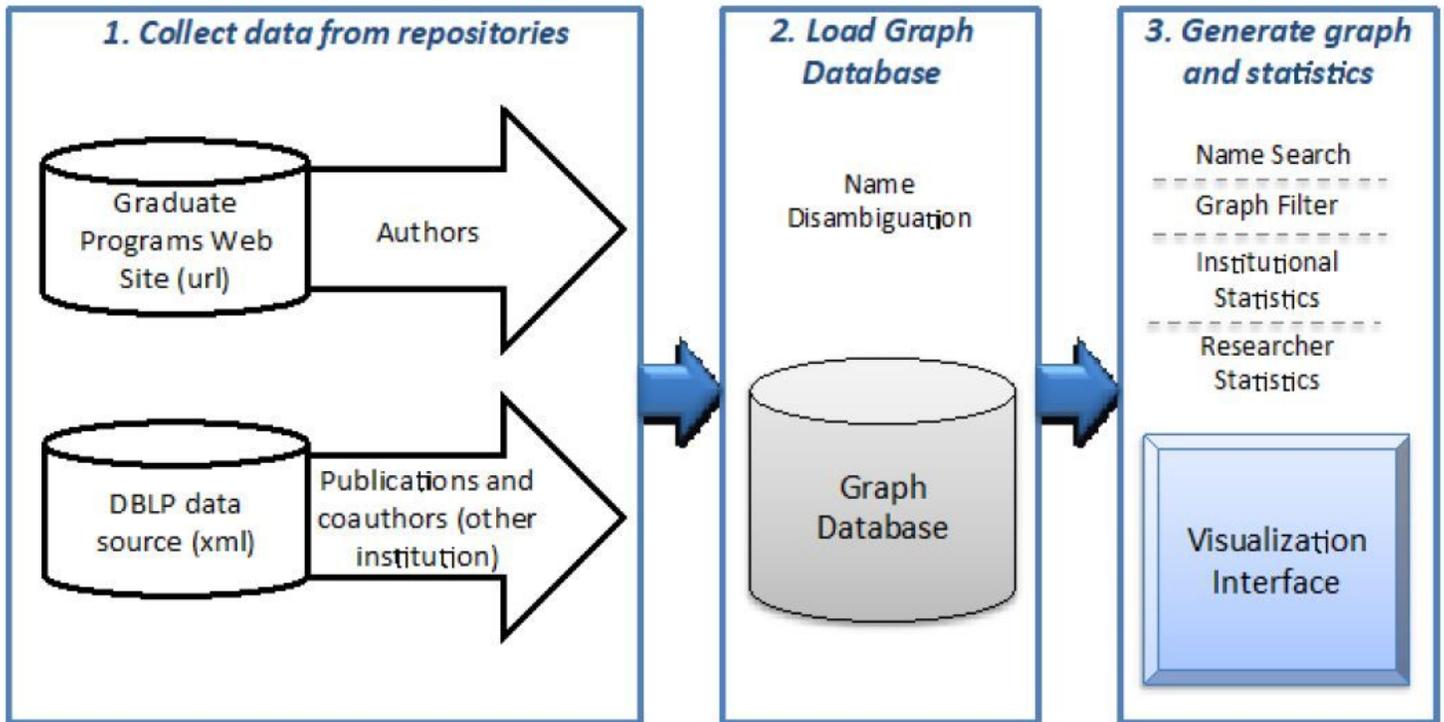


Figure 1

The SCI-synergy architecture.

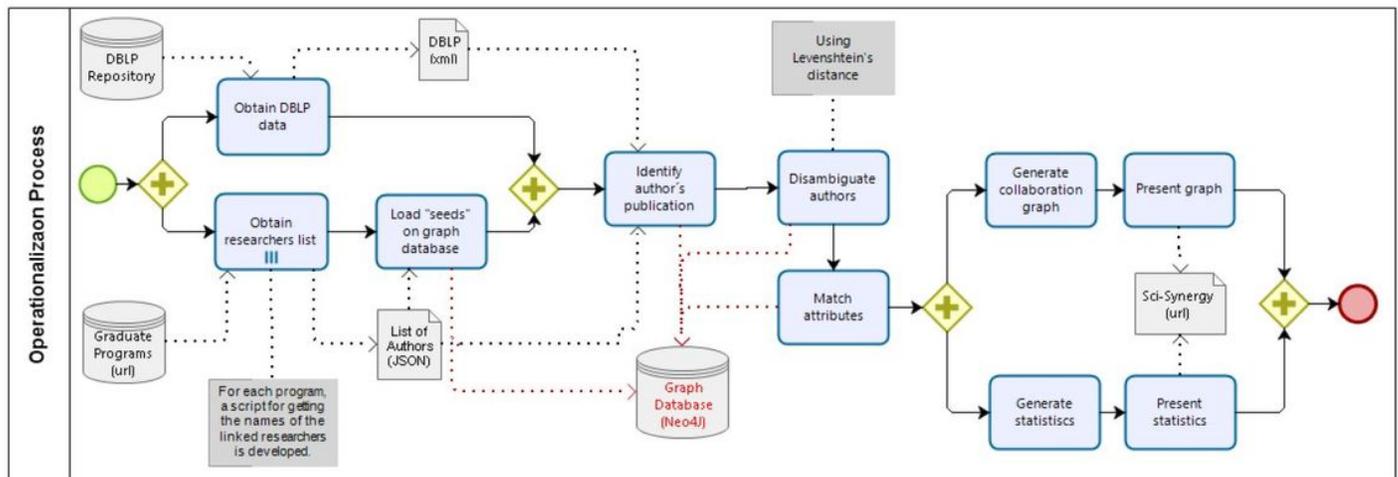


Figure 2

Operationalization process.

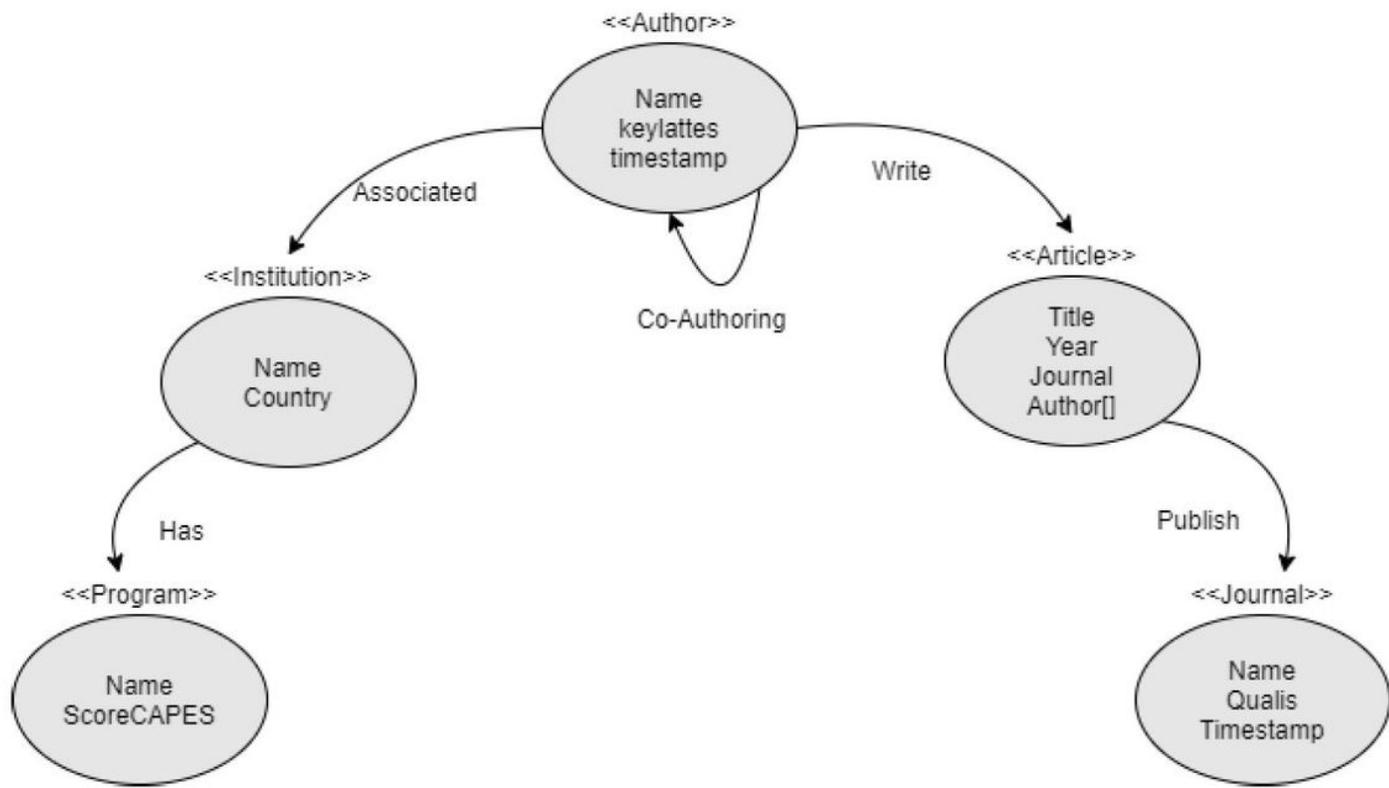


Figure 3

Conceptual data model.

SCI-synergy presents scientific social networks illustrated by Brazilian Graduate Programs

Home

Scientific Network

Network Metrics

Find Researcher

FAQ

Available universities and number of researchers



SCI-synergy data

Total number of graduate programs researchers: 194

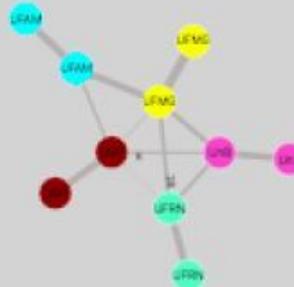
Total number of authors: 8285

Total number of publications: 8599

- Books: 16
- Journal Articles: 3307
- In proceedings: 5576

Intra and Inter-program collaboration network

The edges present the total number of publications in co-authorship between each two programs.



All data come from the dblp computer science bibliography ([DBLP](#)).

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Graph database updated in: 2021-02-03

Site best visualized on Google Chrome or Mozilla Firefox

Figure 4

SCI-synergy home page.

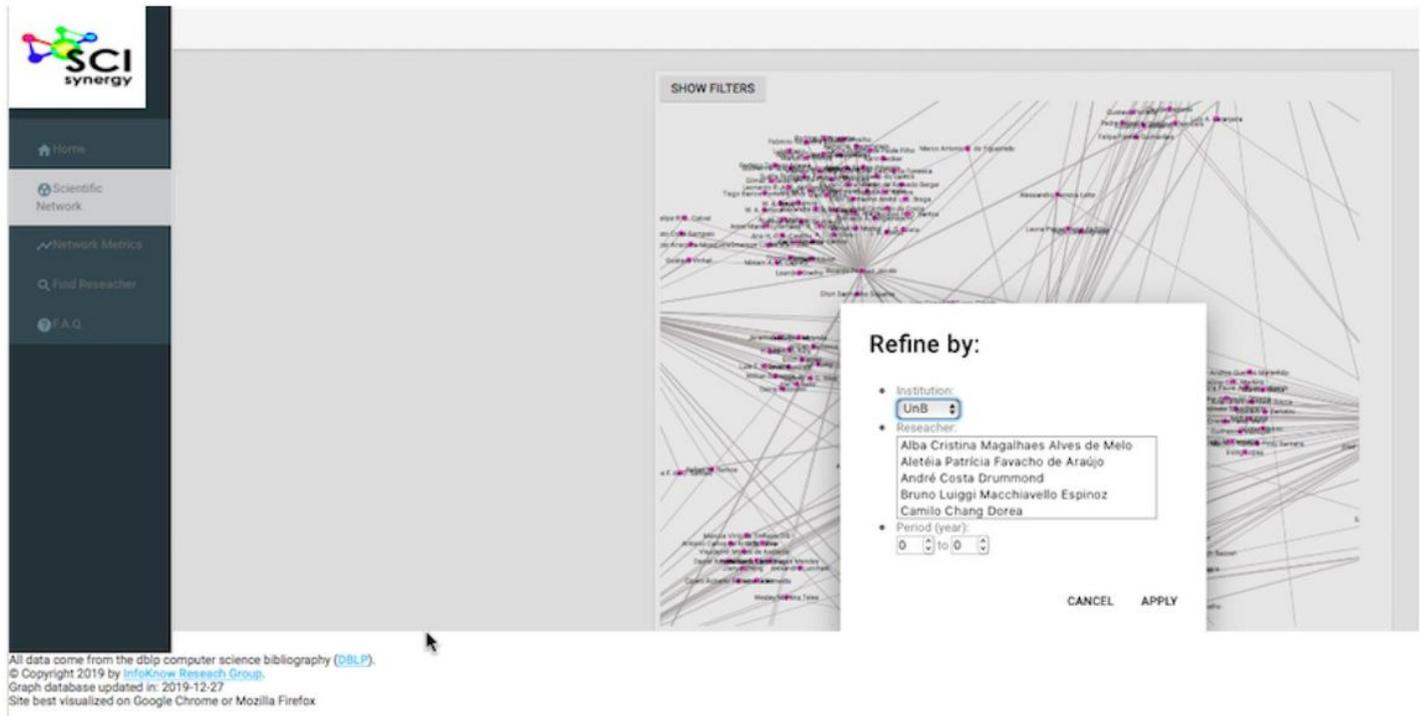


Figure 5

SCI-synergy scientific collaboration network.

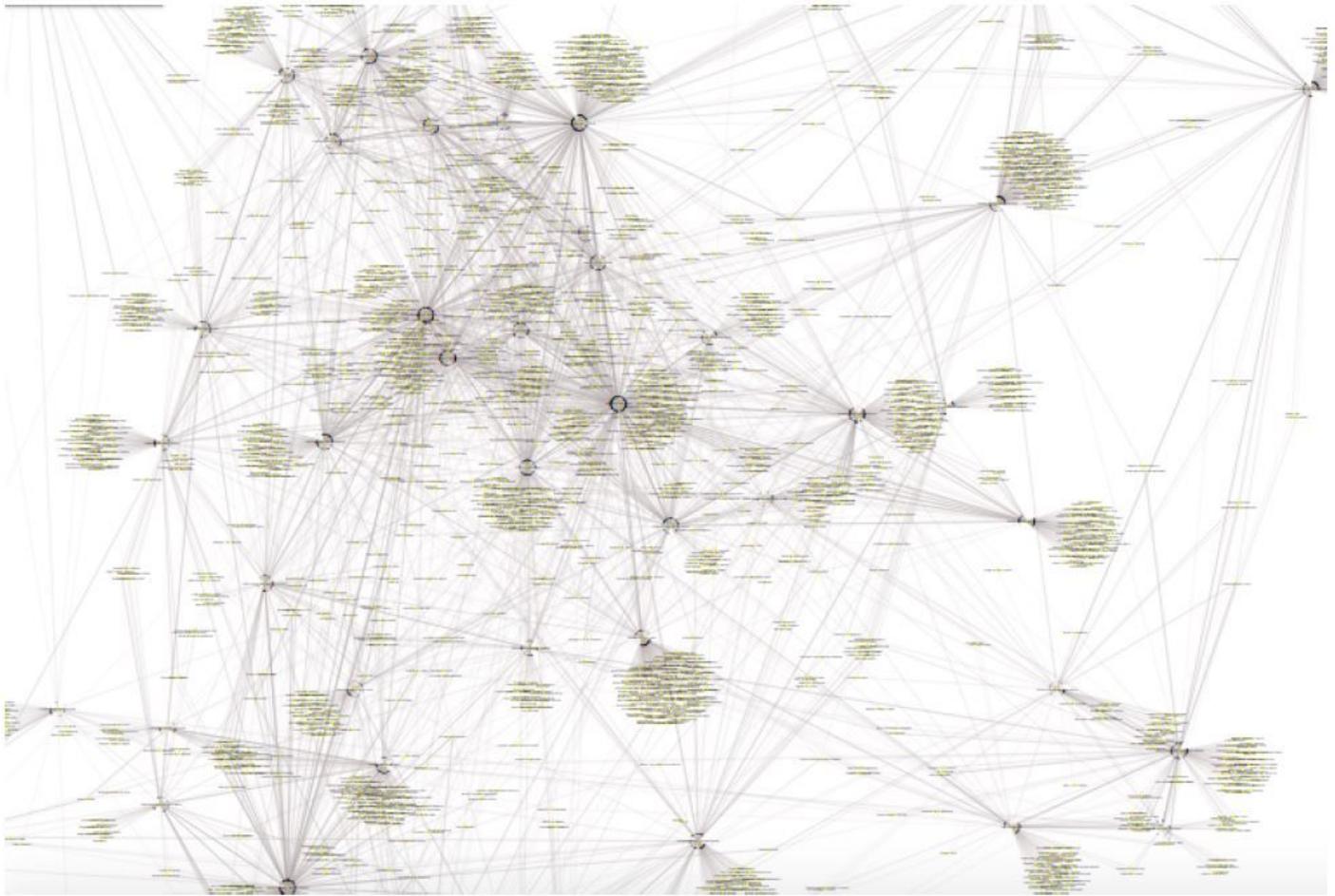


Figure 6

The UFMG scientific collaboration network.

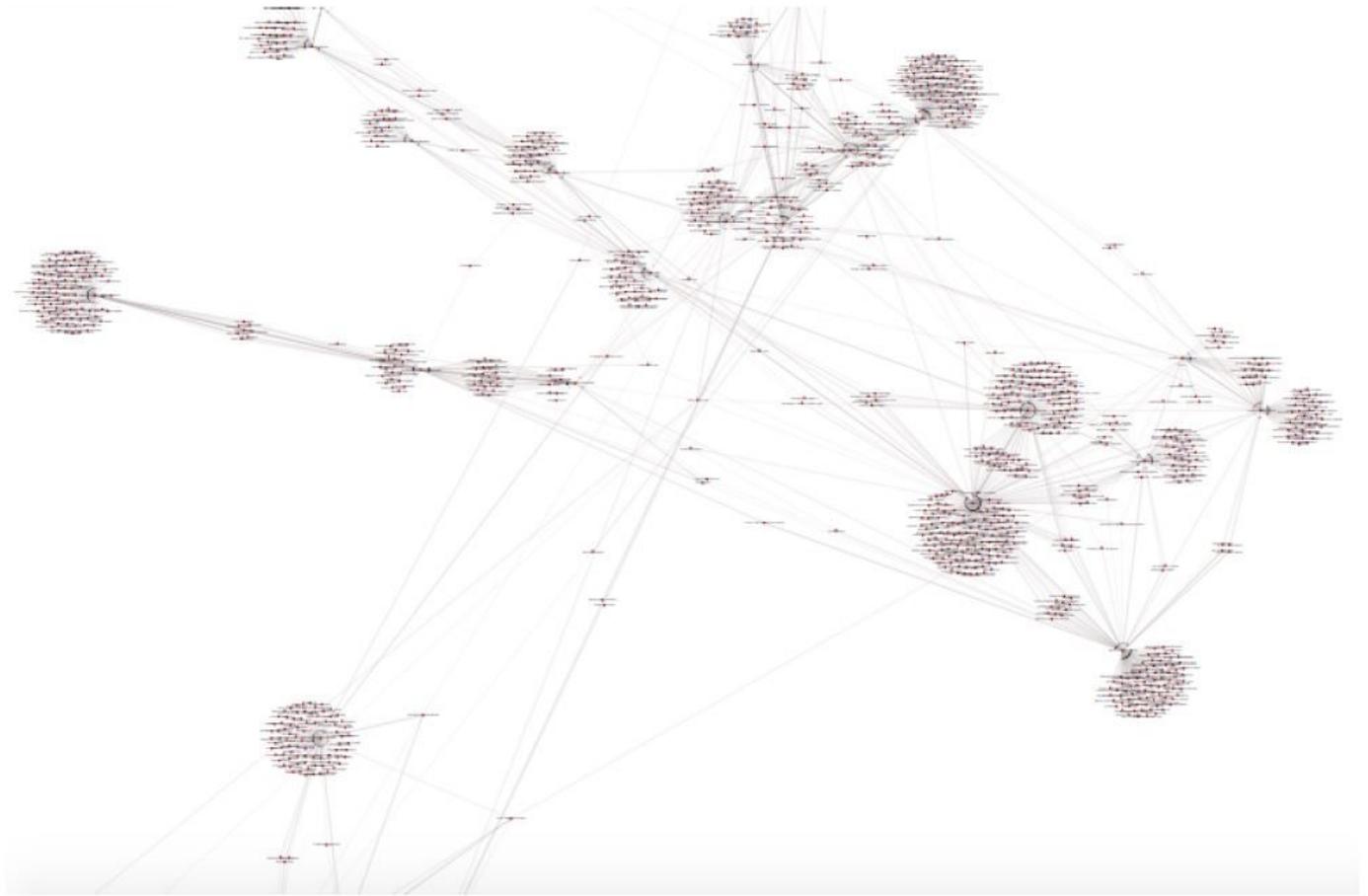


Figure 7

The USP scientific collaboration network.

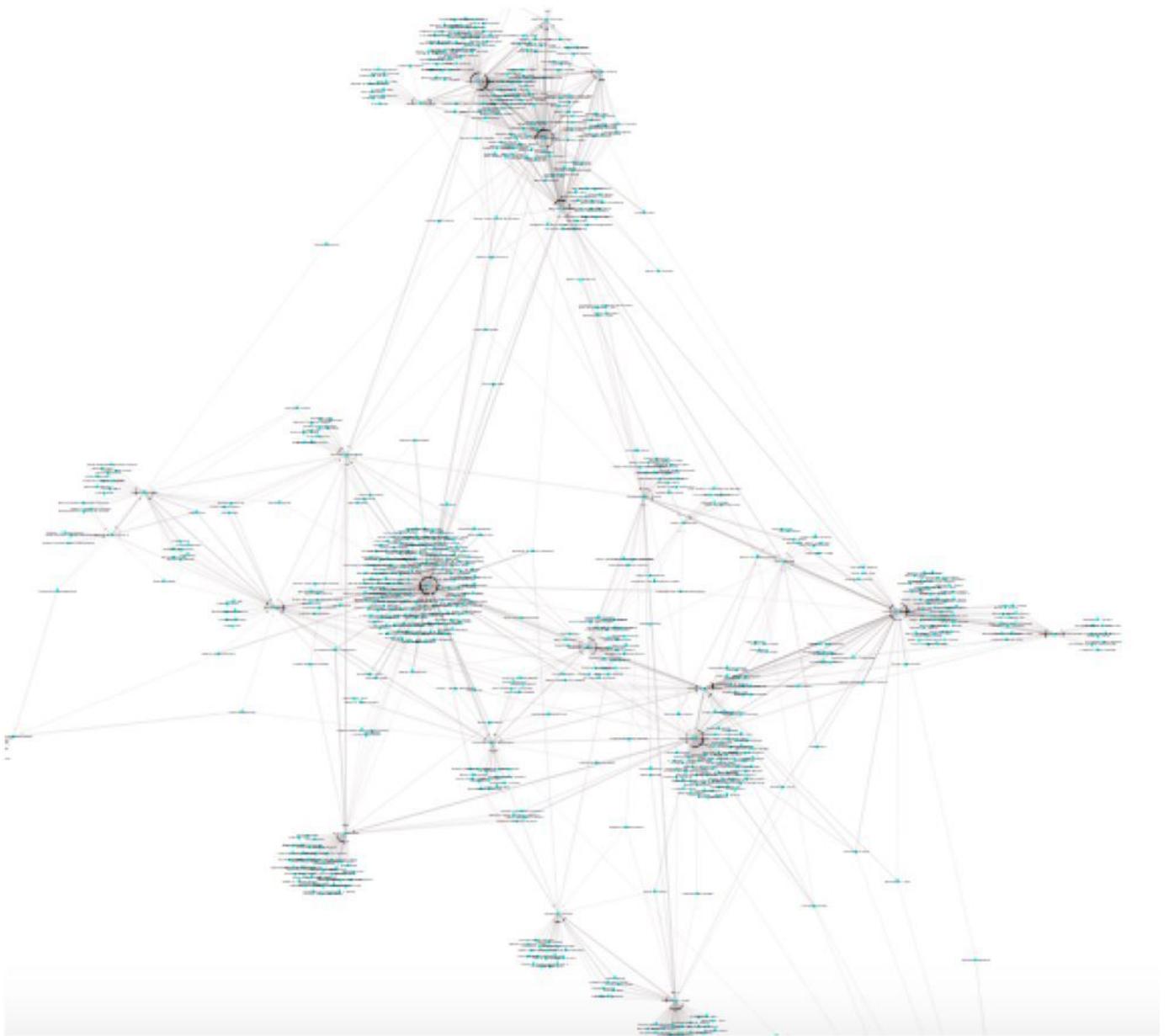


Figure 8

The UFAM scientific collaboration network.

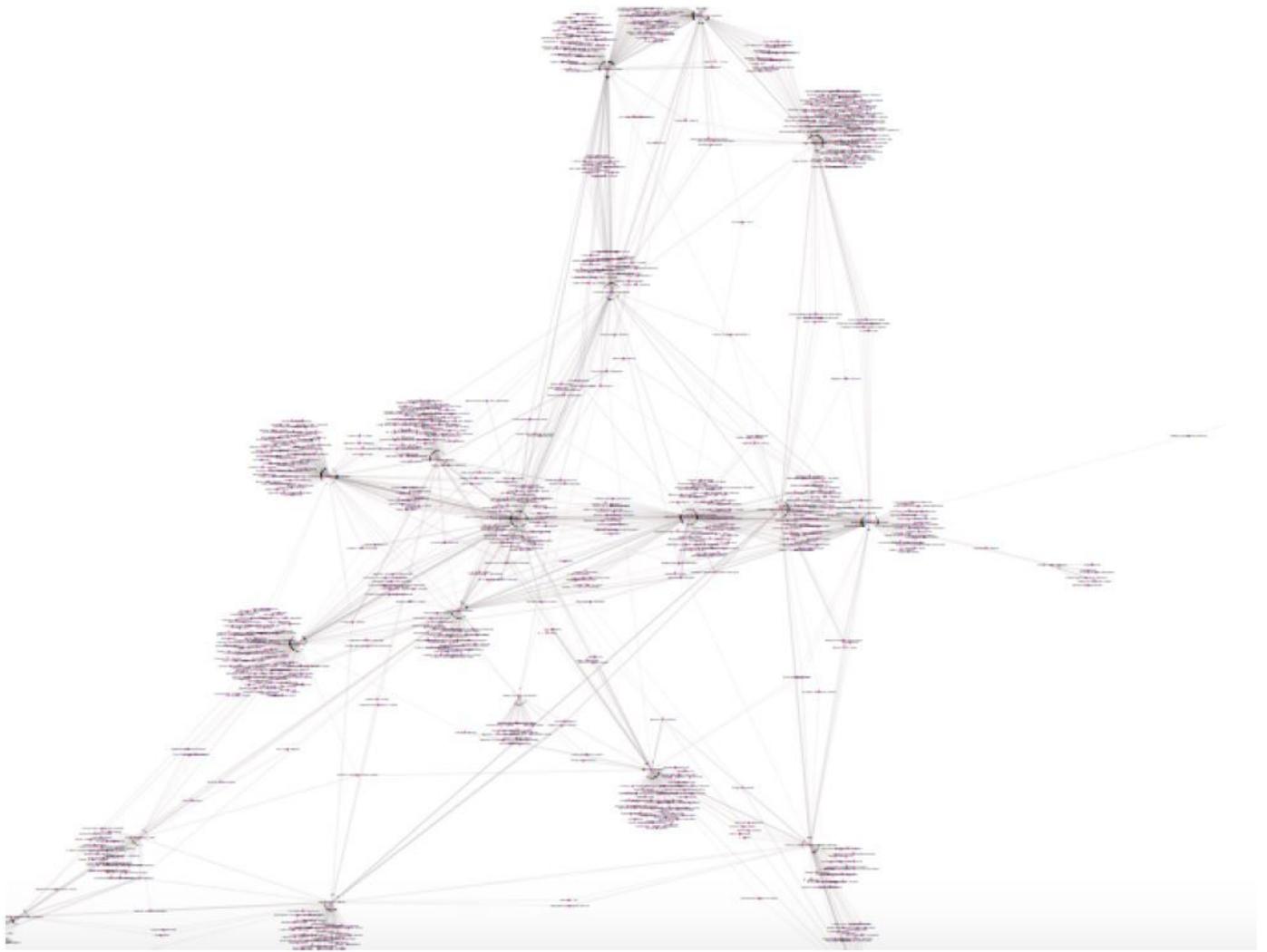


Figure 9

The UnB scientific collaboration network. Figure 10:

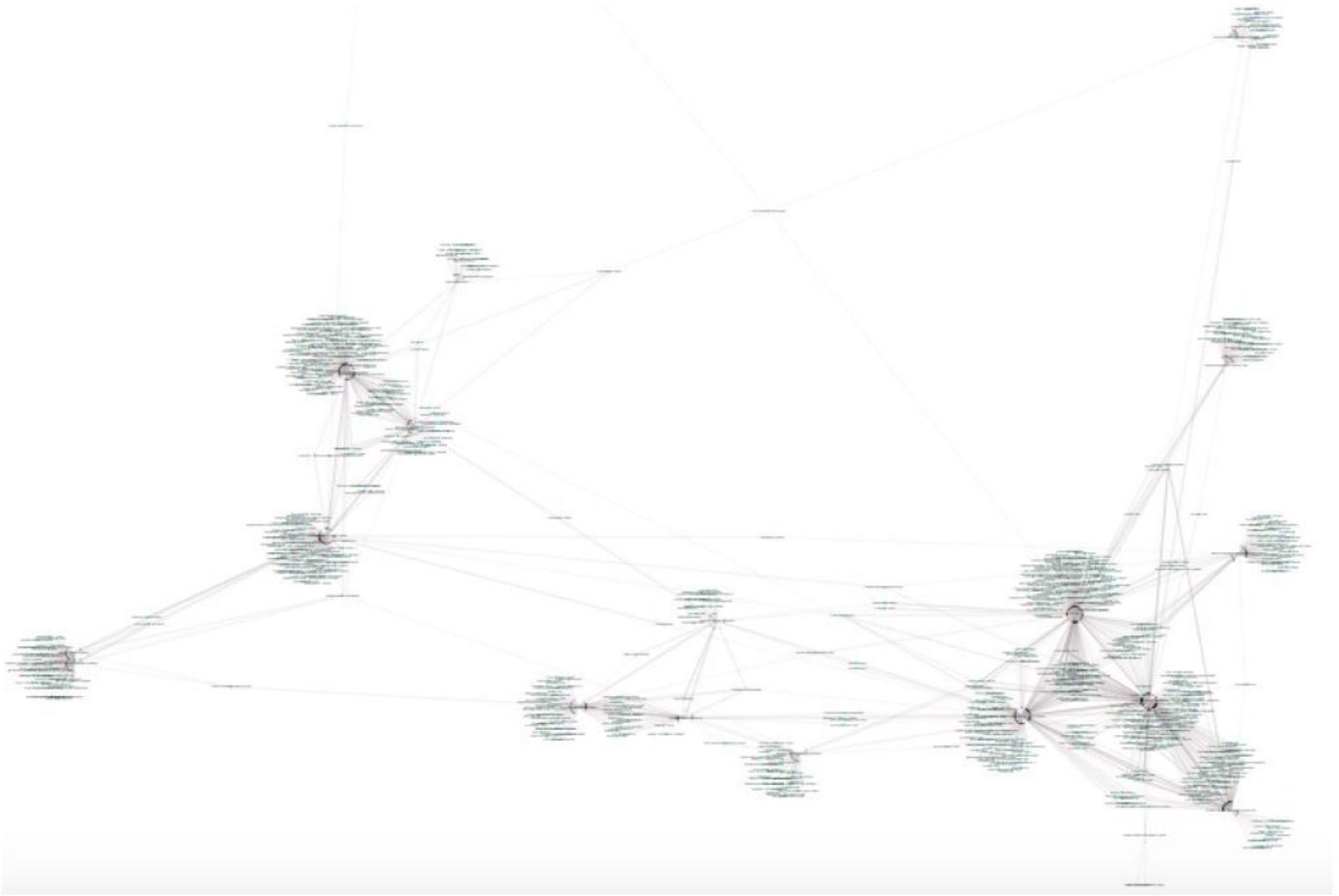
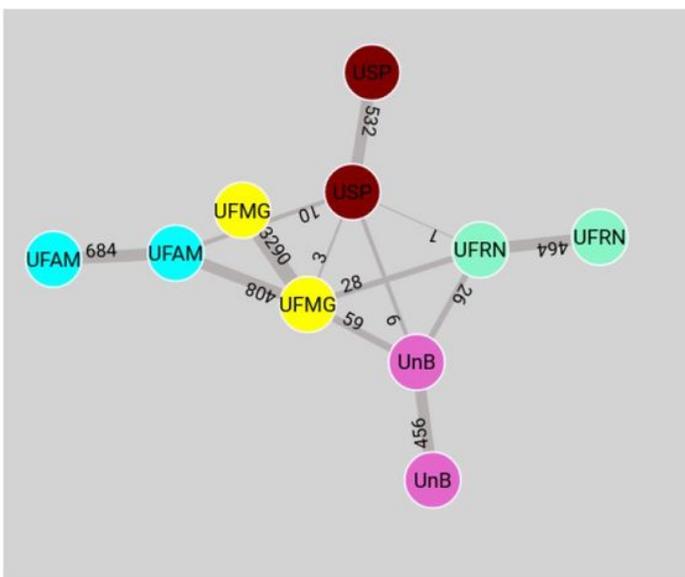
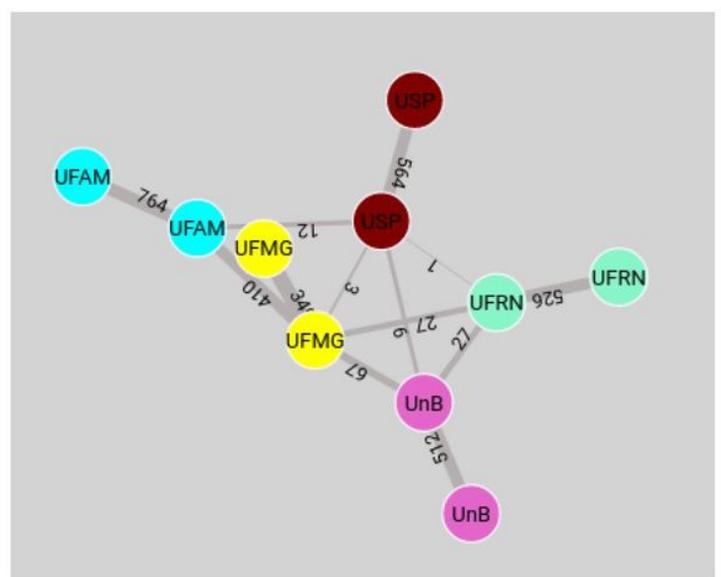


Figure 10

The UFRN scientific collaboration network.



(a)



(b)

Figure 11

Inter and intra-program views. Figure

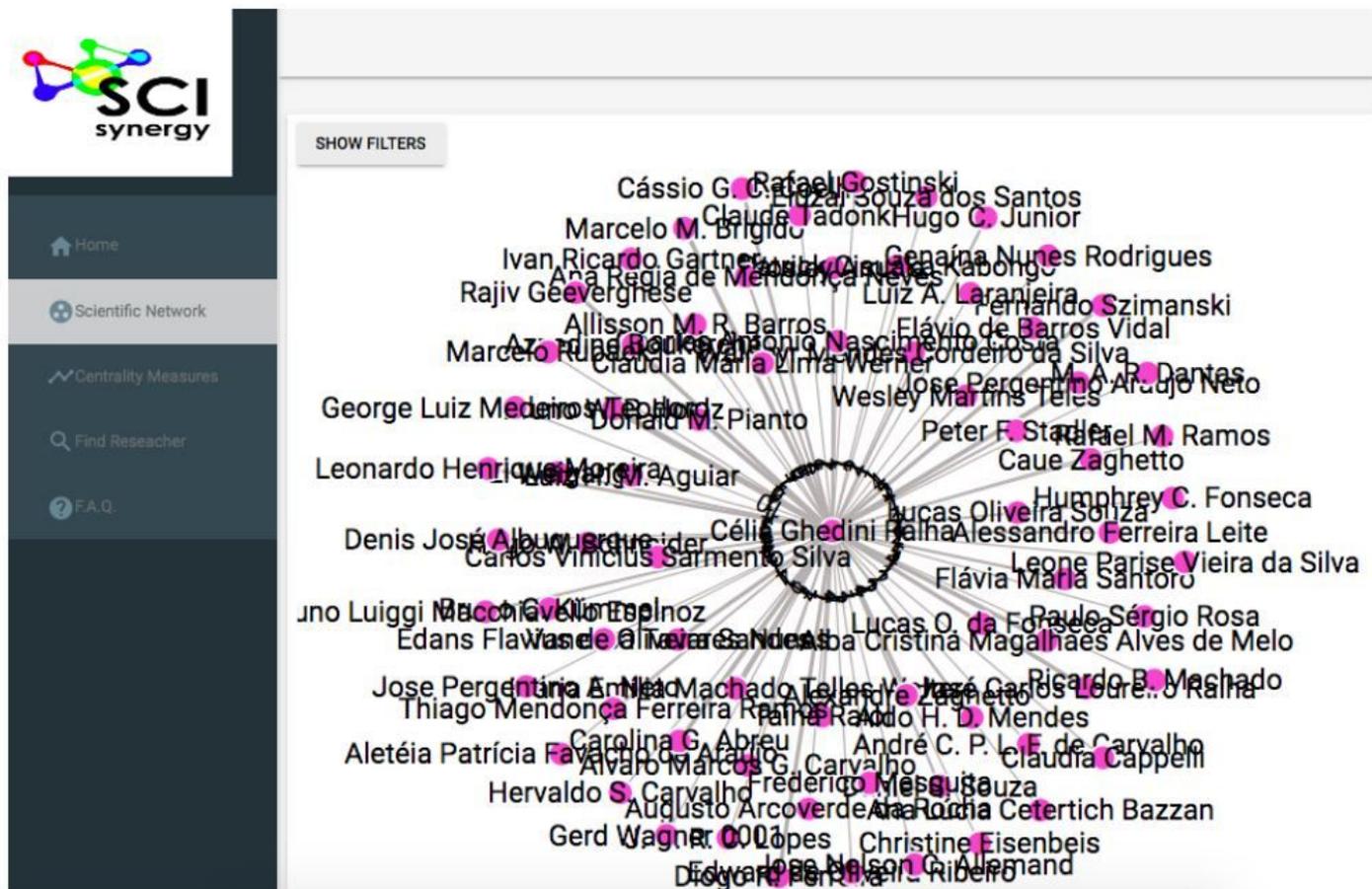


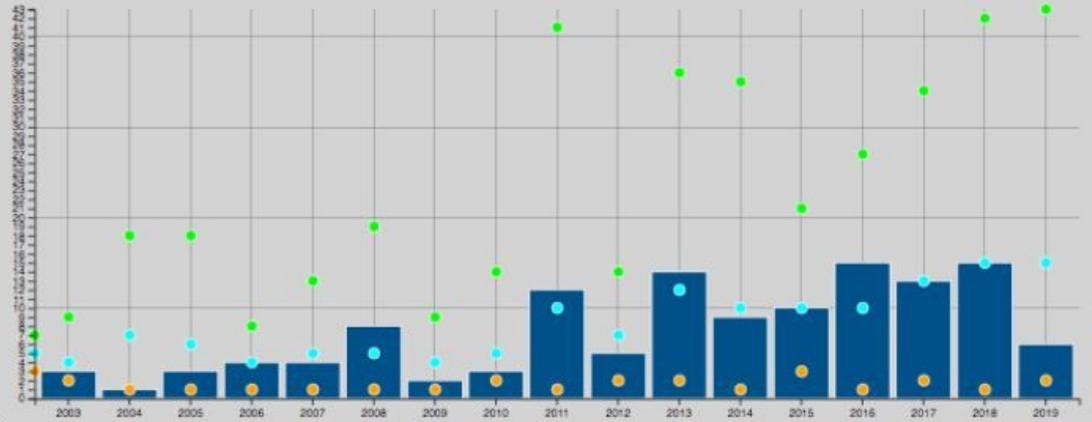
Figure 12

SCI-synergy scientific collaboration network focusing on a specific researcher.

Researcher Collaboration Chart

The chart presents how cooperative the researcher is in his/her graduate program.

Label: ● highest coauthorship number ● medium coauthorship number ● lowest coauthorship number



Total of coauthors (63)

• **2019** (8 coauthorships)

- Jose Pergentino Araujo Neto (2)
- Donald M. Pianto (2)
- Aldo H. D. Mendes (1)
- Luiz A. Lacerda (1)

◦ Cássio G. C. Coelho (1)

◦ Bruno Macchiavello (1)

• **2013** (16 coauthorships)

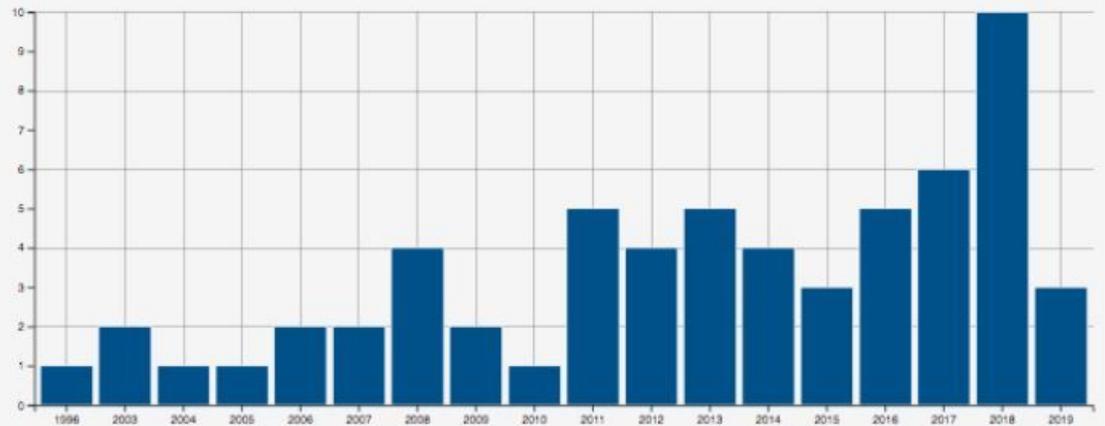
- Wosley Arruda (1)
- Tainá Raiol (1)
- Marcelo M. Brigido (1)

Figure 13

Researcher collaboration aspects.

- Peter F. Stadler (1)
- Vanessa Tavares Nunes (1)
- Flávia Maria Santoro (1)
- Cláudia Maria Lima Werner (1)
- 2014 (9 coauthorships)
 - Ana Régia de Mendonça Neves (1)
 - Álvaro Marcos G. Carvalho (1)
 - Edans Flavius de Oliveira Sandes (1)
 - Alba Cristina Magalhaes Alves de Melo (1)
 - Diogo R. Ferreira (1)
 - Fernando Szimanski (1)
 - Carolina G. Abreu (1)
- 2005 (3 coauthorships)
 - José Carlos Loureiro Ralha (1)
 - Charles Antônio Nascimento Costa (1)
 - Augusto Arcoverde da Rocha (1)
- 2004 (1 coauthorships)
 - José Carlos Loureiro Ralha (1)
- 2003 (3 coauthorships)
 - José Carlos Loureiro Ralha (1)
 - Wesley Martins Teles (1)
 - Weigang Li (1)

Publication Histogram (61)*



The total number of publications for this researcher in dblp database <https://dblp.uni-trier.de>

All data come from the dblp computer science bibliography (DBLP).
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 Graph database updated in: 2019-12-27
 Site best visualized on Google Chrome or Mozilla Firefox

Figure 14

Researcher publication information

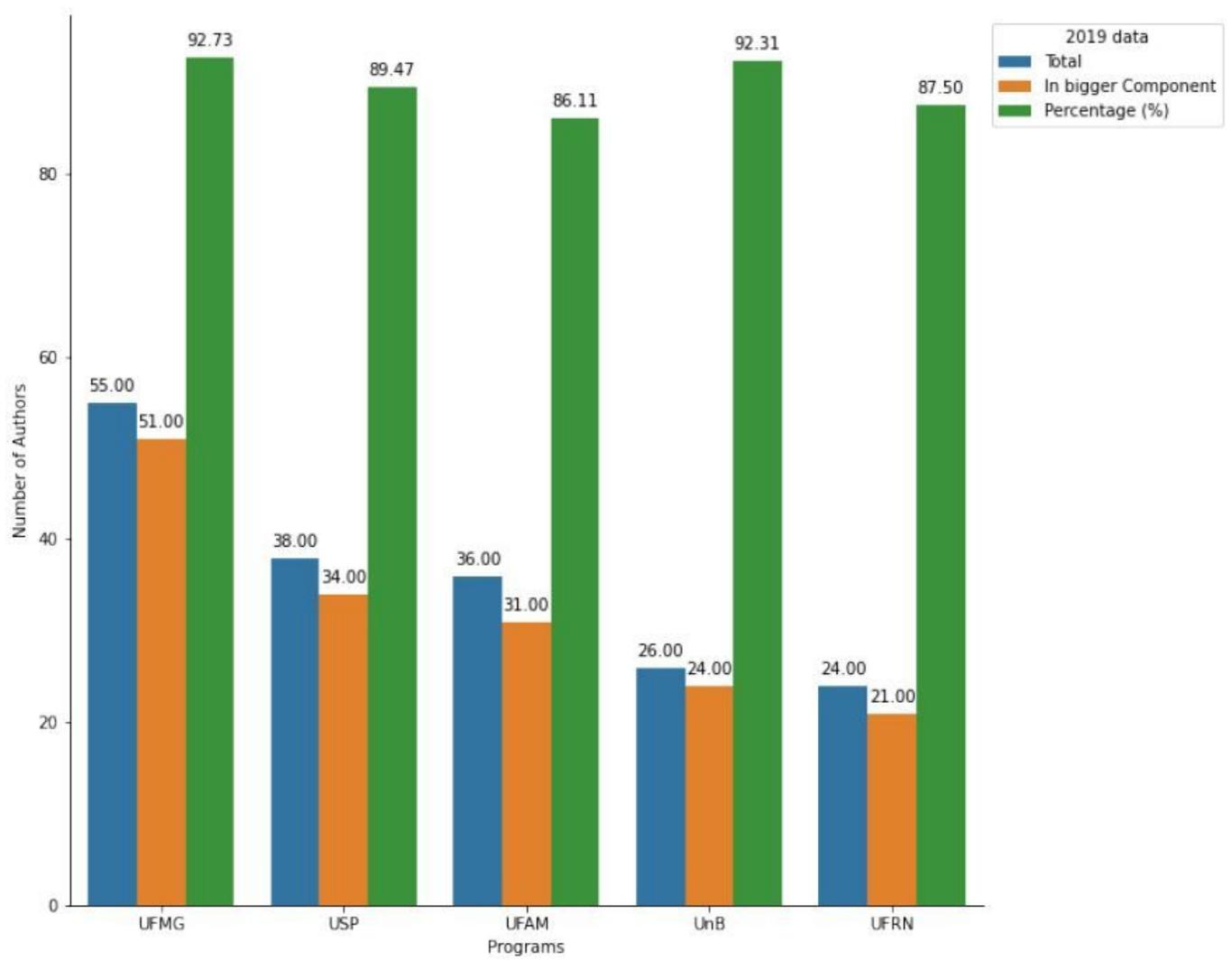


Figure 15

Authors' participation of the bigger component (2019).

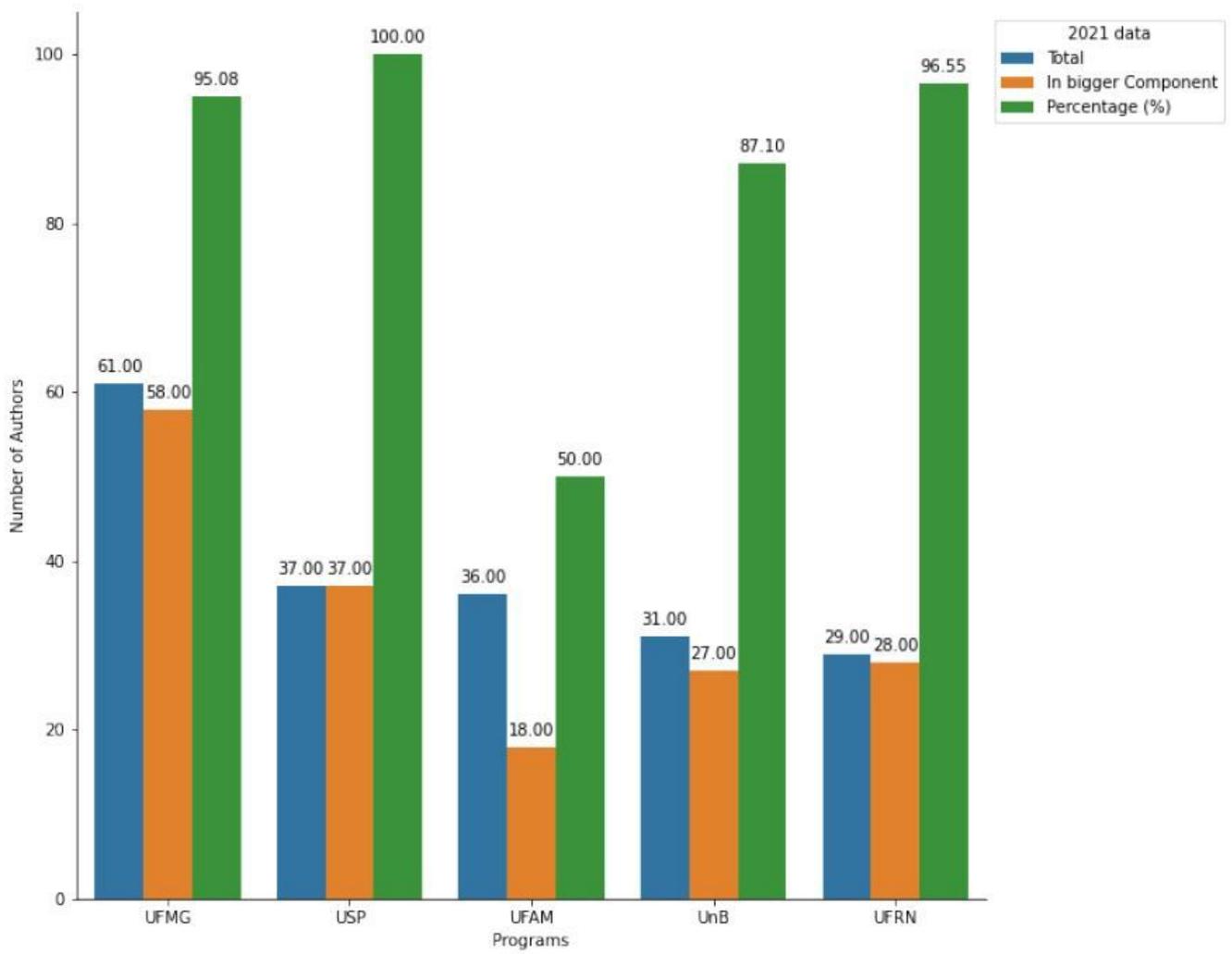


Figure 16

Authors' participation of the bigger component (2021).