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Detecting, identifying and visualizing research groups in co-authorship networks

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Abstract The present paper proposes a method for detecting, identifying and visualizing research groups. The data used refer to nine Carlos III University of Madrid departments, while the findings for the Communication Technologies Department illustrate the method. Structural analysis was used to generate co-authorship networks. Research groups were identified on the basis of factorial analysis of the raw data matrix and similarities in the choice of co-authors. The resulting networks distinguished the researchers participating in the intra-departmental network from those not involved and identified the existing research groups. Fields of research were characterized by the Journal of Citation Report subject category assigned to the bibliographic references cited in the papers written by the author-factors. The results, i.e., the graphic displays of the structures of the socio-centric and co-authorship networks and the strategies underlying collaboration among researchers, were later discussed with the members of the departments analyzed. The paper constitutes a starting point for understanding and characterizing networking within research institutions.

Keywords Scientific collaboration · Research groups · Coauthorship · Network analysis · Information visualization

Introduction

The teamwork intrinsic in scientific activity from the very dawn of science is still characteristic of research today, as evinced by the growing specialization and

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internationalization that has taken place in recent decades (Beaver and Rosen 1978; Harsanyi 1993; Melin and Persson 1996).

Any number of bibliometric and scientometric studies stand as proof of the growing interest in the microanalysis of research activity, focusing on the research group level (Bordons et al. 1995b; Bordons and Zulueta 1997; Zulueta et al. 1999; Zulueta and Bordons 1999). This has been largely due to the fact that guidelines for the concentration of research are among the priorities of scientific policy, in particular measures relating to research management and organization. But it is also because research groups are the basic organizational unit for universities aiming to assume, organize around and acquire a business approach and steer their technological and research activities toward the establishment of links with the surrounding business community (Etzkowitz 2003).

Although studies on the activity, composition and productivity of research groups through micro-level bibliometric indicators provide insight into research structure and dynamics (von Tunzelmann et al. 2003), such analyses have seldom been conducted. This is due to the existence of many types of technical or even technological difficulties, including the application of statistical methods to small quantities or the costs of gathering and processing duly normalized data for detailed analysis involving such minute disaggregation.

Objectives

The present paper proposes a method for detecting, identifying and visualizing research structures. The aim pursued is to contribute to the microanalysis of internal research dynamics at the individual and research group level, based on scientific co-authorship networking by the members of Carlos III University of Madrid (UC3M) departments.

Methods

As noted above, the relevance of research groups has grown to the point that in many disciplines they are now generally regarded to be the basic unit of the research system. Today these groups are becoming a key component of research in many scientific and technological disciplines, while individual work has been losing ground even in Social Science and the Humanities (Bordons et al. 1995a; Zulueta and Bordons 1999).

Definition of a research group

Many attempts have been made to formalize what is meant by research group, one of the most precise definitions being a community of scientists who work together in the approach to and development of research, sharing material and financial resources, but not necessarily organized along the lines of the formal structure of the institution or institutions where the activity is conducted (Zulueta and Bordons 1999). The proposals put forward by the various areas of science to delimit the data identifying research groups refer to such delimitation in different ways. Cohen identified two methodological patterns to delimit groups: result-based and input-based (Cohen 1991). Under the former, researchers in the same department, research partners or co-authors of scientific papers, regardless of their affiliation, are regarded to be members of a research group. In this case the research population is defined on the grounds of co-author details or citations (Noyons et al. 1999).

Productivity studies based on bibliometric techniques constitute an example of this approach, in which teams are represented by author networks deduced from the frequency of co-authorship. Groups are not necessarily administrative or institutional units. On the contrary, such analyses identify operational rather than physical groups (Seglen and Aksnes 2000). This precludes the need for prior information on the unit to be studied. In input-based method, by contrast, author affiliation is required to be able to conduct the analysis. The result-based method, however, omits scientists who do not publish, whereas input-based studies define groups on the basis of administrative agreements that include all members, whether or not they publish. This paper uses a combination of the two patterns defined by Cohen to obtain networks apt for detecting and classifying research groups.

Coauthorship as unit of measurement

The author of a scientific paper is defined to be the person who creates the information and drafts the written document. Consequently, intellectual creativity and originality are the basis of scientific authorship. A scientific document is said to be co-signed if there is more than one author. And it is regarded to be institutionally co-signed when there is more than one author and each is affiliated with a different institution, department or similar.

Despite the limitations of co-authorship-based inventories (Laudel 2002; Melin and Persson 1996; Subramanyam 1983; Vuckovic-Dekic 2003), many a study has used this approach to determine the structure of scientific collaboration and individual researcher status or position. Networking among scientists, in which the links grow out of co-authorship of one or more documents, is often more real from a social network standpoint than institutional networking. While similar to citation and co-citation networks, collaboration networks involve much stronger social ties. Citations imply no acquaintance among authors and may extend over time, whereas co-authorships entail a temporary relationship between colleagues that fall within the scope of social network analysis (Fig. 1). In other words, co-authorship entails stronger social links than bonds based on citation inventories, for it implies that authors are contemporaries and acquaintances; their relationships, therefore, fall within the scope of social networking analysis (Liu et al. 2005).

While co-authorship is not a perfect method for measuring collaboration, it does embody several advantages: it is invariable and reliable, inasmuch as other researchers may access the same series of papers, contributing to the reproducibility of results; it is a practical and inexpensive method of quantifying collaboration; and it can accommodate

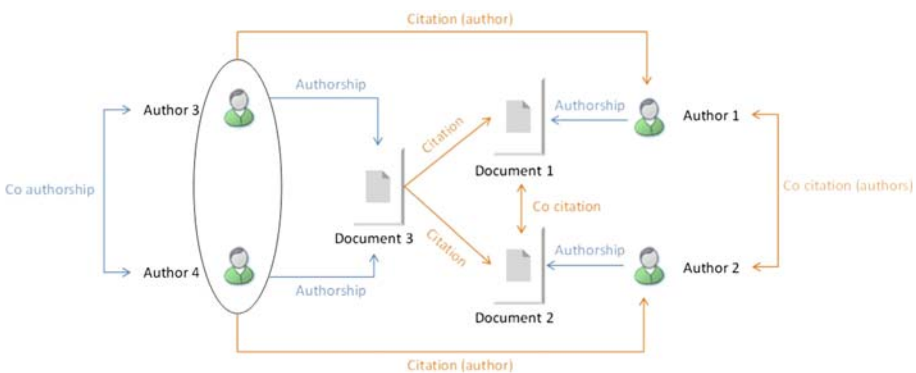

Fig. 1 Combined network of authors and papers (adapted from Ichise et al. 2006)

very large samples, providing for more statistically significant results (Katz 1992; Katz and Martin 1997; Miquel et al. 1989; Smith and Katz 2000).

Data

A relational database built with records for the period 1990–2004 taken from the Web of Science (SCI-expanded, SSCI and A&HCI), in which at least one author was affiliated with the UC3M, was used for the bibliometric analysis of the research conducted in the institution. The Institute for Scientific Information (presently Thomson Reuters) assigns each journal one or several subject categories. Journal Citation Reports (JCR) for both Science and Social Science for the years analyzed was the reference used to assign each paper a subject (ISI category).

Data refinement

Once the assumption that a group can be defined from a collection of published papers signed by a series of authors is adopted, it necessarily follows that their names must be standardized and processed for that purpose (Calero et al. 2006). Two problems are commonly encountered in connection with the author field: homonymy (two authors with the same name) and synonymy (the existence of different variations on an author's name). To obviate these difficulties, the SCImago group used ad hoc software that avoids homonymy by combining author and institution and synonymy by combining author and paper (Gálvez and Moya-Anegón 2007; Gálvez and Moya-Anegón 2006) (Fig. 2).

Network generation

After the entire dataset was defined and the authors and departments comprising the population to be analyzed were identified, the resulting displays were generated showing

Fig. 2 SCImago ad hoc software for refining affiliation

the information in the form of social networks that depict the authors as nodes and their co-written papers as interconnections. The maps originally plotted using the Kamada–Kawai algorithm (Kamada and Kawai 1989) were subsequently exported to Scalable Vector Graphics (W3C 2005). This very valuable format provides for interactive displays, features a data-on-demand function and improves representation usability (Eisenberg 2002; Geroimenko and Chen 2005; Herrero-Solana and Hassan 2006; Moya-Anegón et al. 2004; Vargas-Quesada and Moya-Anegón 2007).

Identification of research groups

Since groups play an essential role in the properties of complex structures, the identification and analysis of their nature is an important task that is being undertaken in fields as diverse as Information Technology, Sociology, Bibliometrics and Biochemistry, to determine the informal organization and nature of information flows within these complex systems.

Nonetheless, the group, understood to mean a stable pattern of transactions among individuals or groups of individuals, is a variable concept (Monfort 2004). Depending on the network, these groups may arise naturally and intuitively, or have to be extracted artificially (Ichise et al. 2006).

Groups, then, are subsets of closely related nodes on a graph. Analysis of nodal groups is a valuable tool for understanding networks. Such analysis entails essentially two tasks: detection and identification. The former consists in discovering the different groups existing in the network, while the latter focuses on characterizing each subset of nodes extracted from the initial network.

Many detection algorithms use hierarchical clustering techniques. Such algorithms are two-phased: the first defines the metrics that represent internode similarity. The second uses extraction methods defined on the basis of two possible types of metrics (Balakrishnan and Deo 2006), agglomerative and divisive (Donetti and Muñoz 2004; Newman 2004a, b; Radicchi et al. 2004; Reichardt and Bornholdt 2004; Wu and Huberman 2004).

But in addition to hierarchical extraction methods, which are only useful if the structure is to be interpreted in terms of sets of separate communities, others based on locating network communities by statistical analysis of the raw data are also available (Palla et al. 2005). Of the many such schemes in place, the one chosen for the present study is factor analysis, which has been widely used in similar analyses (Chen et al. 2001; Chen and Carr 1999a, b; Chen and Paul 2001; Ding et al. 2000; McCain 1990; White and McCain 1997). Its use is justified in that groups can be defined on the grounds of the structure of interconnections or, in other words, the premise that the members of each group tend to choose and by chosen by the same partners. Consequently, membership in a group is established on the basis of similarities between the choices made by and about each author. Such conditions make choices tend to exhibit reciprocity, while the factors obtained and rotated form a simple structure. In short, the notion of group proposed is not a single common space in which all the participants are interlinked. Rather, the members of each group share a distinctive perceptive structure with respect to their work, matching a different dimension in factor space in each of the resulting communities.

We used three different thresholds, one for factors and two for variables. The criterion adopted to stop the extraction of factors was an eigenvalue equal to or greater than 1. Then, variables of each factor were ordered by their factor loading in decreasing order. The limit establishes for belonging the factor was a value equal to or greater than 0.5. Finally, since the groups can be identified and aggregated in terms of common characteristics, the JCR subject categories corresponding to the bibliographic references cited in the papers by the authors constituting the factor were taken into consideration when assigning the name that characterizes each factor. In this case, the threshold proposed was a factor loading of at least 0.7 (Ding et al. 2000; Moya-Anegón et al. 1998). The use of ISI categories to detected communities allow to depict specialties in which is divided the departmental research activity. Be it said in this regard that when a given characteristic (working in the same speciality, in this case) is relevant to the choice of authorship, the existence of two or more groups related to that common characteristic, but in different factors, cannot be ruled out (Vargas-Quesada and Moya-Anegón 2007).

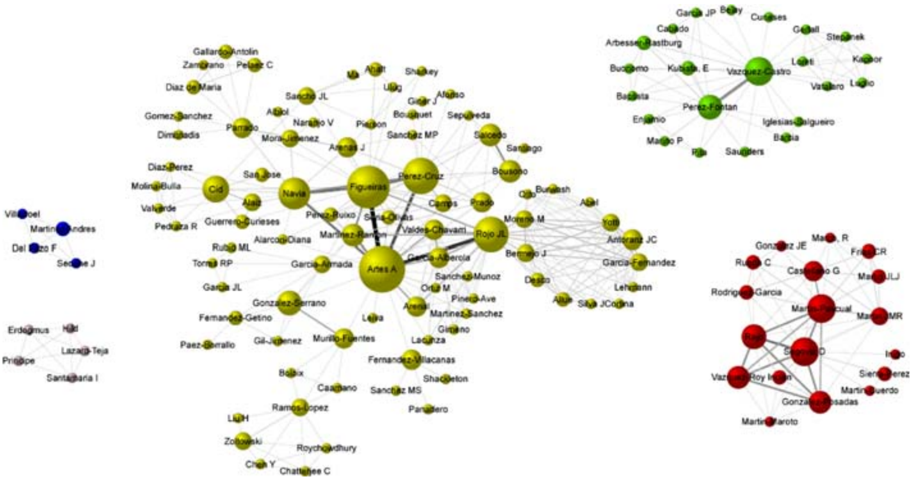

Fig. 3 Components. Communication technologies network (2000–2004)

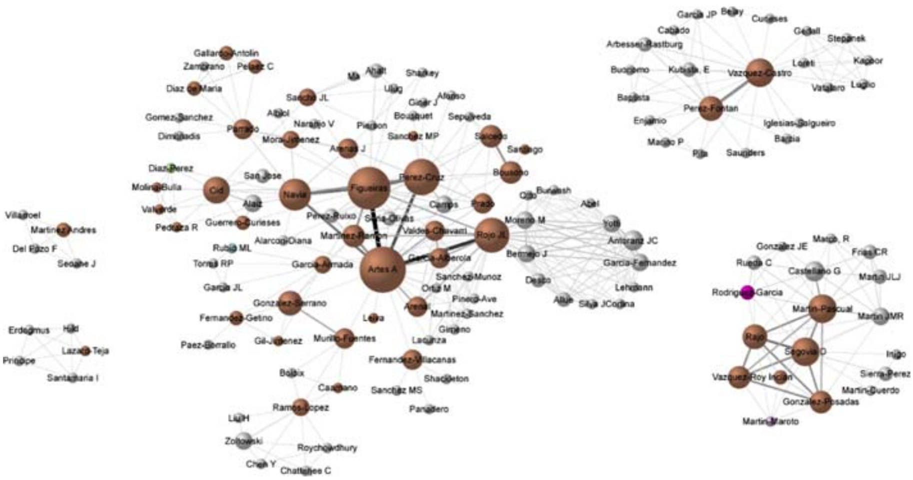

Fig. 4 Department membership. Communication technologies network (2000–2004)

Results

The formulation of co-authorship networks under the premises described in the section on methodology provides fuller insight into the evolution of collaboration in each of the units analyzed. The unit chosen for this study was the Department of Communication Technologies.

Figure 3 shows the network for the period 2000–2004. The size of the nodes denotes production volume. The colours represent membership in one of the five network components. The larger the number of papers written jointly by any two authors, the thicker and darker are the lines representing the bonds between them.

By incorporating input-based data (Fig. 4), the use of colour to differentiate actors in the visual information supplements the result-based network. Likewise, further to the premises

Table 1 Groups detected at the Communication Technology Department according to factor loading (eigenvalue $\geq$ 1)

2000–2004				
Factor	Eigenvalue	Variance (%)	Cum (%)	Ratio
1	12.78	8.9	8.9	1.23
2	10.41	7.2	16.1	1.22
3	8.56	5.9	22	1.22
4	7.04	4.9	26.9	1.18
5	5.97	4.1	31.1	1.21
6	4.93	3.4	34.5	1.01
7	4.86	3.4	37.9	1.01
8	4.80	3.3	41.2	1.07
9	4.48	3.1	44.3	1.12
10	4.01	2.8	47.1	1.04
11	3.86	2.7	49.8	1.03
12	3.76	2.6	52.4	1.05
13	3.57	2.5	54.9	1.09
14	3.28	2.3	57.1	1.08
15	3.03	2.1	59.3	1.09
16	2.78	1.9	61.2	1.11
17	2.50	1.7	62.9	1.08
18	2.31	1.6	64.5	1.07
19	2.17	1.5	66	1.03
20	2.11	1.5	67.5	1.07
21	1.98	1.4	68.9	1.02
22	1.94	1.3	70.2	1.06
23	1.82	1.3	71.5	1.06
24	1.72	1.2	72.7	1.09
25	1.58	1.1	73.8	1.02
26	1.56	1	74.9	1.12
27	1.40	1	75.8	1.01
28	1.38	1	76.8	1.13
29	1.21	0.8	77.6	1.07
30	1.13	0.8	78.4	1.21

introduced by Moreno, the use of variation in node size facilitates the visualization of each actor's characteristic features and the position of the vertices (Moreno 1953).

The application of factor analysis to the departmental network matrix identified 30 underlying factorial groups on the grounds of the structure of their choice of bonds (Table 1). The colours of the nodes in Fig. 5 indicate membership in the groups identified.

The detail in Fig. 6 was obtained with the zoom function on the visualization format used. The ovals delimit two of the groups identified.

As noted in the description of the methodology, the JCR categories for the bibliographic references cited by the authors constituting the factors were used to interpret the results (Table 2). Although common characteristics can be attributed to the factorial groups in a

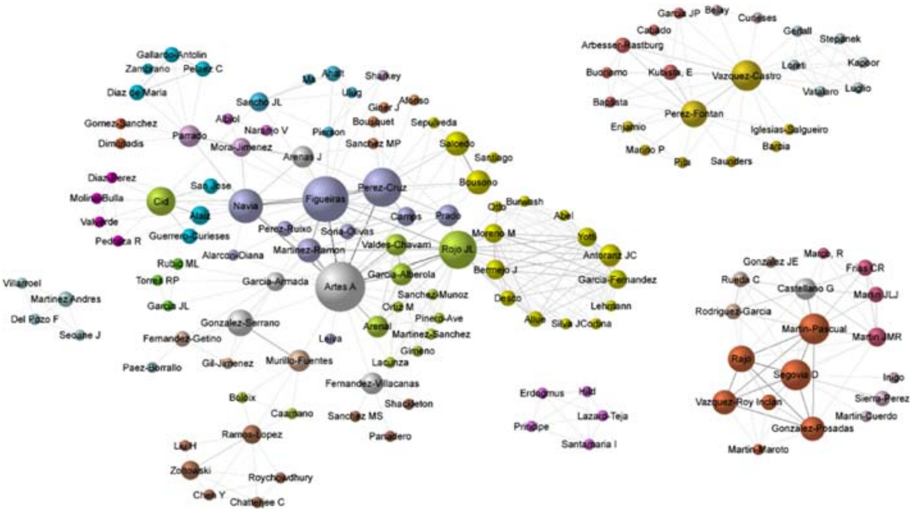

Fig. 5 Research groups. Communication technologies network (2000–2004)

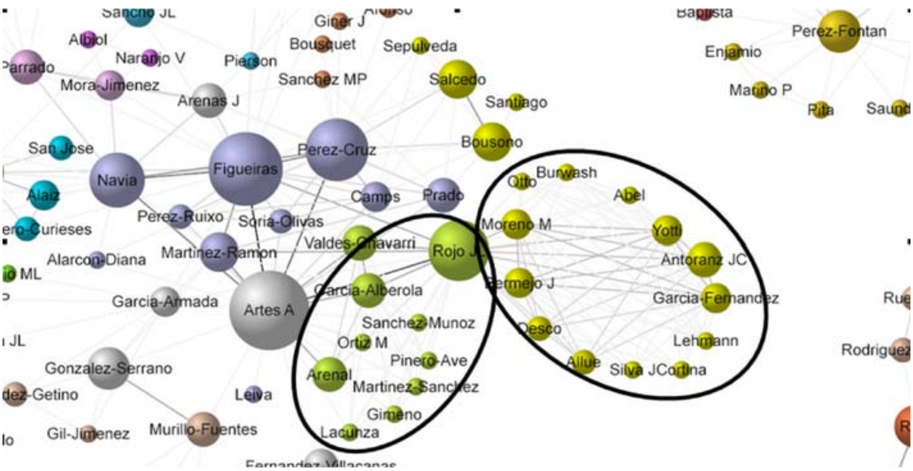

Fig. 6 Detail of two research groups

number of ways and the research speciality classification chosen is coarse-grained, the advantage of this approach is that it is inherent in the data themselves.

In the example discussed, the two groups detected had common research profiles centred on the development of communication technologies applied to biomedicine and shared an author who plays the role of structural hole between the two (Fig. 7).

The systematic application of the classification of each actor in each group is shown in Fig. 8, which highlights the five specialities constituting the department's organizational chart: Electrical and Electronic Engineering, Telecommunications, Computer Science, Biomedicine and Education. The visualization chosen identifies the groups that work in the same speciality but that do not share authorship.

Table 2 Sample of members belonging to groups detected at the Communication Technology Department (factor loading ≥ 0.5)

2000–2004					
Factor	1	Factor	2	Factor	3
Lacunza	0.88	Silva	0.93	Saunders	0.90
Gimeno	0.88	Cortina	0.93	Enjamio	0.84
Sánchez-Muñoz	0.88	Yotti	0.92	Marino	0.84
Martínez-Sánchez	0.88	Bermejo	0.92	Pita	0.84
Ortiz	0.88	Antoranz	0.92	Iglesias	0.80
Pinero	0.88	García-Fernández	0.92	Barcia	0.80
Valdés	0.86	Moreno	0.92	Vázquez-Castro	0.64
García-Alberola	0.86	Allue	0.91	Pérez-Fontán	0.62
Arenal	0.85	Desco	0.91		
Martínez M	0.56	Burwash	0.86		
Rojo	0.51	Lehmann	0.86		
		Abel	0.86		
		Otto	0.86		

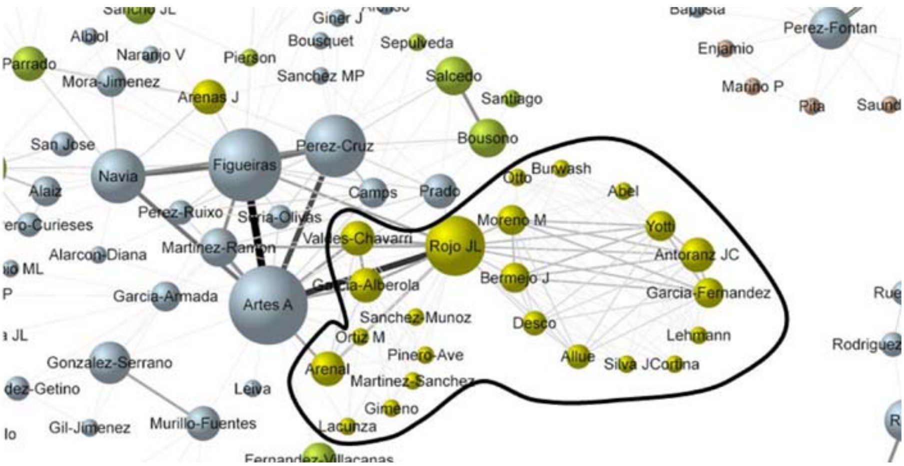

Fig. 7 Interpretation of research groups on the grounds of JCR categories

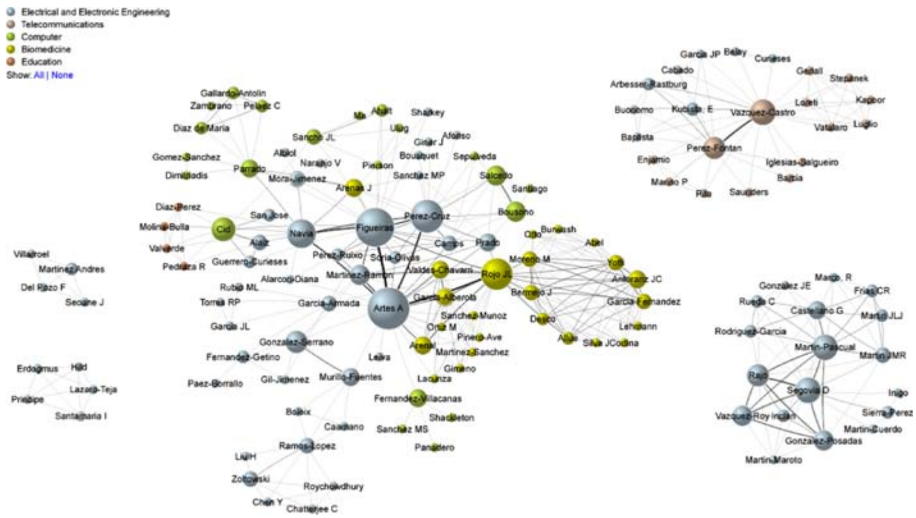

Fig. 8 Specialties. Communication technologies network (2000–2004)

Conclusions

A functional representation of research groups was obtained from co-authorship-based links through a suitable combination of result-based studies and administrative information from the university itself (input).

The resulting groups showed not only individual relationships, but how these relationships are able to draw authors together in larger structures. The visualizations obtained revealing the social and intellectual ties in the form of components whose isolation is an initial approximation of the concept of research group.

The metaphor chosen, a map of the stars, along with the visual aids consisting in colour-coding, forms, thicknesses and sizes, the inclusion of legends, labels and brief explanations, the orderly distribution of information in the space available and the formulation of different groups, guarantee the credibility of the information presented, the convenience of search functionalities, the existence of different perspectives for a given reality, the elimination of distortion of the original data and the presentation of a large amount of coherent information in a limited amount of space.

The method proposed proves to be useful and valid for detecting and identifying research groups defined on the basis of the structure of the choice of co-authorship bonds, with no need to disassemble the resulting networks or isolate any of their components. The result is a series of communities, each of which shares guidelines and objectives distinctly different from those of all the others, based on their research work.

Detection and identification of communities with Factor Analysis is a useful tool for experts in bibliometric and scientometric studies. Likewise, the networks obtained are a useful framework for decision making. In the particular case of UC3M, this work allows a detailed analysis of the different departments studied, in addition to the comparison of the research outputs of groups and specialties in three respects: bibliometric indicators, structural indicators and hybrid indicators (combining bibliometric and structural indicators).

The validation of the results obtained by the professors of the department concerned is encouraging. These experts claimed that the resulting graphs suitably and realistically depict the social as well as the academic relationships formed within the organization, and constitute valuable visual tools containing detailed information on the development and evolution of the department's social capital. They nonetheless recommended replacing the JCR classification with one that can label specializations more precisely and specifically adapted to their field of research.

This paper raises new challenges for the analysis of the properties of co-authorship networks, such as the observation of their organizational forms; the nature of their information flows; the prominence of and interaction between the actors; internal group functions within the complex system of which they form part, deduced from a combination of bibliometric and structural indicators; and the evolution of networks and groups that shed light on their respective "life cycles" by including information over time to observe their birth, transformation through aggregation or segregation and, as appropriate, disappearance. Lastly, the extension and comparison of this methodology to higher order aggregations (scientific, regional, national and international domains) is a very promising line of research.

References

Balakrishnan, H., & Deo, N. (2006). Discovering communities in complex networks. *Proceedings of the 44th Annual Southeast Regional Conference* (pp. 280–285). New York: Association for Computing Machinery.

Beaver, D., & Rosen, R. (1978). Studies in scientific collaboration. Part I. The professional origins of scientific co-authorship. *Scientometrics, 1*, 65–84.

Bordons, M., & Zulueta, M. A. (1997) Comparison of research team activity in two biomedical fields. *Scientometrics, 40*(3), 423–436.

Bordons, M., Zulueta, M. A., Cabrero, A., & Barrigón, S. (1995a). Identifying research teams with bibliometric tools. *Proceedings of the 5th International Conference of the International Society for Scientometrics and Informetrics* (pp. 83–91). Medford: Learned Information.

Bordons, M., Zulueta, M. A., Cabrero, A., & Barrigón, S. (1995b). Research performance at the micro level: analysis of structure and dynamics of pharmacological research teams. *Research Evaluation, 5*(2), 137–142.

Calero, C., Buter, R., Cabello, C., & Noyons, E. C. M. (2006). How to identify research groups using publication analysis: An example in the field of nanotechnology. *Scientometrics, 66*(2), 365–376.

Chen, C., & Carr, L. (1999a). *Visualizing the evolution of a subject domain: a case study. IEEE visualization* (pp. 449–452). San Francisco: IEEE Computer Society.

Chen, C., & Carr, L. (1999b). A semantic-centric approach to information visualization. *Proceedings of the 3rd International Conference on Information Visualisation* (pp. 18–23). Londres: IEEE Computer Society.

Chen, C., & Paul, R. J. (2001). Visualizing a knowledge domain's intellectual structure. *IEEE Computer, 34*(3), 65–71.

Chen, C., Paul, R. J., & O'Keefe, B. (2001). Fitting the jigsaw of citation: information visualization in domain analysis. *Journal of the American Society for Information Science and Technology, 52*(4), 315–330.

Cohen, J. E. (1991). Size, age and productivity of scientific and technical research groups. *Scientometrics, 20*(3), 395–416.

Ding, Y., Chowdhury, G. G., & Foo, S. (2000). Journal as markers of intellectual space: Journal co-citation analysis of information retrieval area, 1987–1997. *Scientometrics, 47*(1), 55–73.

Donetti, L., & Muñoz, M. A. (2004). Detecting network communities: A new systematic and efficient algorithm. *Journal of Statistical Mechanics: Theory and Experiment, 10012*, 1–15.

Eisenberg, J. D. (2002). *SVG essentials*. Beijing: O'Reilly.

Etzkowitz, H. (2003). Research groups as quasy-firms: The invention of the entrepreneurial university. *Research Policy, 32*(1), 109–121.

Gálvez, C., & Moya-Anegón, F. (2006). The unification of institutional addresses applying parametrized finite-state graphs (P-FSG). *Scientometrics, 69*(2), 323–345.

Gálvez, C., & Moya-Anegón, F. (2007). Standardizing formats of corporate source data. *Scientometrics, 70*(1), 3–26.

Geroimenko, V., & Chen, C. (2005). *Visualizing information using SVG and X3D: XML-based technologies for the XML-based Web*. London: Springer.

Harsanyi, M. A. (1993). Multiple authors, multiple problems. Bibliometrics and the study of scholarly collaboration: a literature review. *Library and Information Science Research, 15*, 325–354.

Herrero-Solana, V., & Hassan, Y. (2006). Metodología para el desarrollo de interfaces visuales de recuperación de información: Análisis y comparación. *Information Research, 11*(3), from http://informationr.net/ir/11-3/paper258.html.

Ichise, R., Takeda, H., & Uemaya, K. (2006). Exploration of researchers' social network for discovering communities. In: *New Frontiers in Artificial Intelligence*. New York: Springer-Verlag (Joint JSAI Workshop, 2005).

Kamada, T., & Kawai, S. (1989). An algorithm for drawing general undirected graphs. *Information Processing Letters, 31*(1), 7–15.

Katz, J. S. (1992). Bibliometric assessment of intranational University-University collaboration. Dissertation, University of Sussex, Brighton.

Katz, J. S., & Martin, B. R. (1997). What is research collaboration? *Research Policy, 26*, 1–18.

Laudel, G. (2002). What do we measure by co-authorship? *Research Evaluation, 11*(1), 3–15.

Liu, X., Bollen, J., Nelson, M. L., & van de Sompel, H. (2005). Co-authorship networks in the digital library research community. *Information Processing and Management, 41*, 1462–1480.

McCain, K. W. (1990). Mapping authors in intellectual space: A technical overview. *Journal of the American Society for Information Science, 41*(6), 433–443.

Melin, G., & Persson, O. (1996). Studying research collaboration using co-authorships. *Scientometrics, 36*(3), 363–377.

Miquel, J. F., Okubo, Y., Narváez, N., & Frigoletto, L. (1989). Les scientifiques sont-ils ouverts à la coopération internationale? *La Recherche, 20*(206), 116–118.

Monfort, N. (2004). *Discovering communities through information structure and dynamics: A review of recent research*, Pennsylvania State University (Technical Report, no MS-CIS-04–18).

Moreno, J. L. (1953). *Who shall survive? Foundations of sociometry, group psychotherapy and sociodrama*. New York: Beacon House.

Moya-Anegón, F., Jiménez Contreras, E., & Moneda Corrochano, M. (1998). Research fronts in library and information science in Spain. *Scientometrics, 42*(2), 229–246.

Moya-Anegón, F., Vargas-Quesada, B., Herrero-Solana, V., Chinchilla-Rodríguez, Z., Corera-Álvarez, E., & Muñoz-Fernández, F. J. (2004). A new technique for building maps of large scientific domains based on the cocitation of classes and categories. *Scientometrics, 61*(1), 129–145.

Newman, M. E. J. (2004a). Detecting community structure in networks. *European Physical Journal B, 38*, 321–330.

Newman, M. E. J. (2004b). Coauthorship networks and patterns of scientific collaboration. *Proceedings of the National Academy of Sciences of the U S A, 101*(Suppl 1), 5200–5205.

Noyons, E. C. M., Moed, H. F., & van Raan, A. F. J. (1999). Integrating research performance analysis and science mapping. *Scientometrics, 46*(3), 591–604.

Palla, G., Derényi, I., Farkas, I., & Vicsek, T. (2005). Uncovering the overlapping community structure of complex networks in nature and society. *Nature, 435*, 814–818.

Radicchi, F., Castellano, C., Cecconi, F., Loreto, V., & Parisi, D. (2004). Defining and identifying communities in networks. *Proceedings of the National Academy of Sciences of the U S A, 101*(9), 2658–2663.

Reichardt, J., & BornHoldt, S. (2004). Detecting fuzzy community structures in complex networks with a potts model. *Physical Review Letters, 93*(21), 218701-1–218701-4.

Seglen, P. O., & Aksnes, D. W. (2000). Scientific productivity and group size: a bibliometric analysis of Norwegian microbiological research. *Scientometrics, 49*(1), 125–143.

Smith, D., & Katz, J. S. (2000). *Collaborative approaches to research*. Brighton: Science Policy Research Unit.

Subramanyam, K. (1983). Bibliometric studies of research collaboration: A review. *Journal of Information Science, 6*(1), 33–38.

Vargas-Quesada, B., & Moya-Anegón, F. (2007). *Visualizing the structure of science*. Berlin: Springer.

von Tunzelmann, N., Ranga, M., Martin, B. R., & Geuna, A. (2003). *The effects of size on research performance: A SPRU review*. Brighton: University of Sussex.

Vuckovic-Dekic, L. (2003). Authoship-coauthorship. *Archive of Oncology, 11*(3), 211–212.

White, H. D., & McCain, K. W. (1997). Visualization of literatures. *Annual Review of Information Science and Technology, 32*, 99–168.

W3C. Scalable Vector Graphics (SVG) Full 1.2 Specification. [Online]. World Wide Web Consortium, 2005. Retrieved October 6, 2007, from http://www.w3.org/TR/SVG12.

Wu, F., & Huberman, B. A. (2004). Finding communities in linear time: A physics approach. *European Physical Journal B, 38*(2), 331–338.

Zulueta, M. A., & Bordons, M. (1999). A global approach to the study of teams in multidisciplinary research areas through bibliometric indicators. *Research Evaluation, 8*(2), 111–118.

Zulueta, M. A., Cabrero, A., & Bordons, M. (1999). Identificación y estudio de grupos de investigación a través de indicadores bibliométricos. *Revista Española de Documentación Científica, 23*(3), 333–347.