

# Mapping scientific institutions

Sebastian Grauwin · Pablo Jensen

Received: 4 May 2011  
© Akadémiai Kiadó, Budapest, Hungary 2011

**Abstract** We have developed a set of routines that allows to draw easily different maps of the research carried out in a scientific institution. Our toolkit uses OpenSource elements to analyze bibliometric data gathered from the Web Of Science. We take the example of our institution, *ENS de Lyon*, to show how different maps, using co-occurrence (of authors, keywords, institutions...) and bibliographic coupling can be built. These maps may become a valuable tool for discussing institutions' policies, as they offer different views on the institution at a global scale.

**Keywords** Institutions · Maps · Heterogeneous · Governance

## Introduction

Quantitative studies of science has developed methods and tools to better understand the organization of scientific fields (Small 1999) and their evolution (Glänzel 2003; Chavalarias and Cointet 2009; Cambrosio et al. 2006). Global science maps (Small 1999; Klavans and Boyack 2009; Small 1973; Börner and Scharnhorst 2009; Börner 2010; Noyons 2004; Leydesdorff and Rafols 2009; Rafols and Leydesdorff 2010; Agarwal and Skupin 2008; Cobo et al. 2011; Leydesdorff and Persson 2010) have become feasible

---

S. Grauwin · P. Jensen (✉)  
Université de Lyon, Lyon, France  
e-mail: pablo.jensen@ens-lyon.fr

S. Grauwin · P. Jensen  
Institut des Systèmes Complexes Rhône-Alpes (IXXI), Lyon, France

S. Grauwin · P. Jensen  
Laboratoire de Physique, École Normale Supérieure de Lyon and UMR CNRS 5672,  
69007 Lyon, France

P. Jensen  
Laboratoire d'Économie des Transports, Université Lyon 2 and UMR CNRS 5593,  
69007 Lyon, France

recently, offering a tentative overall view of scientific fields and fostering dreams of a “science of science” (Börner and Scharnhorst 2009). In this article, we propose a more modest but less explored mapping, that of single scientific institutions. The scope is to achieve a global point of view on the institutions that no individual can have, in order to understand their organization, their strong and weak points, the papers or authors that link different Departments or disciplines... Such maps may become important as policy tools as it is difficult to have such a global view of scientific institutions.

Recently, Rafols and Leydesdorff have suggested a simple way to picture the disciplinary weight of an institution (Rafols and Leydesdorff 2010). This method is rapid and can be carried out online. As it uses Web of Science (<http://apps.isiknowledge.com/>) “subject categories” as relevant subdisciplines to project the data, it has the advantage of enabling a comparison across different institutions or years. The drawback of this rigid projection skeleton is that it preselects, without local information, the relevant communities. As acknowledged by Rafols and Leydesdorff (2010): “The two characteristics that make overlay maps so useful for comparison, their fixed positional and cognitive categories, are also inevitably, their major limitations and a possible source of misreadings. Since the position in the map is only given by the attribution in the disciplinary classification, it does not say anything about the direct linkages between the nodes.”

Here we propose different ways of mapping scientific institutions based on the articles published with that address (and not the journals as in Rafols and Leydesdorff 2010). We do not propose a real methodological innovation, but rather an approach (and a toolbox) that allows to draw several maps of the chosen scientific institution. More specifically, we show four different ways of mapping our institution, ENS de Lyon, and show how each of these gives different information. Our scope is to display—in an accessible (but not too simplistic) way—the institution’s complexity thus helping to generate discussions on its policy among its scientists.

## Methodology

### Data extraction

The “Ecole normale supérieure de Lyon” (ENS de Lyon), focused on Natural sciences, was created in Lyon in 1987 after a move from Saint-Cloud in the suburbs of Paris. In 2010, it merged with the “Social sciences and Humanities” Ecole Normale Supérieure. Today, it gathers 350 researchers, 270 professors, 390 administrative and technical personnel and a budget of more than 110 million Euros. A simple query (performed in January 2011) in the ISI Web of Knowledge database (<http://apps.isiknowledge.com/>) yields 7,584 papers containing an *ENS de Lyon* address (mostly under the form “Ecole Normal Super Lyon”, but also “ENS-LYON” and “ENS de Lyon”). We had access to the period 1899–2011. We have used all the available databases, namely (figures in [] refer to the number of papers retrieved from that specific database) : Science Citation Index Expanded [7,100], Social Sciences Citation Index (SSCI) [69], Arts and Humanities Citation Index [74], Conference Proceedings Citation Index-Social Science (CPCI-S) [984], Conference Proceedings Citation Index-Social Science and Humanities (CPCI-SSH) [10], Index Chemicus (IC) [93]. We save the “Full records” of all these articles, the records containing authors, journal, year of publication, title, keywords (given by the authors and/or ISI Web of Science), subjects, addresses (institutions, cities and countries), and the list of references of the articles. It is well-known that Social sciences and Humanities (especially French ones)

and, to a lesser degree, computer science, are not well represented in Web of Science. Therefore, our maps mainly deal with the natural sciences at ENS de Lyon. We have also noted that several publications from Computer Science are not retrieved from Web of Science. Therefore, the interpretation of the results for this area should be taken with caution.

Records are parsed and gathered in MySQL tables, which renders the handling of the data more straightforward. Simple frequency analysis of the records allows to get a first global representation of the institution. Our method uses the relations present in the data (Börner et al. 2003) to display different perspectives on the inner structure of an institution.

### Bibliographic coupling

Links between articles are calculated through their common references. The bibliographic coupling (BC) similarity between two articles  $i$  and  $j$  is defined as Kessler (1963):

$$\omega_{ij} = \frac{|\mathcal{R}_i \cap \mathcal{R}_j|}{\sqrt{|\mathcal{R}_i||\mathcal{R}_j|}} \quad (1)$$

where  $\mathcal{R}_i$  is the set of references of article  $i$ .

In comparison to co-citation link (which is the more usually used measure of articles similarity), BC offers two advantages: it allows to map recent papers (which have not yet been cited) and it deals with all published papers (whether cited or not). The reason why weighted links are used is that they reinforce the dense (in terms of links per article) regions of the BC networks. This reinforcement facilitates the partition of the network into meaningful groups of cohesive articles, or communities. A widely used criterion to measure the quality of a partition is the modularity function (Girvan and Newman 2004; Fortunato and Barthélemy 2007), which is roughly is the number of edges inside communities (as opposed to crossing between communities), minus the expected number of such edges if the network were randomly produced. We compute the graph partition using the efficient heuristic algorithm presented in Blondel et al. (2008).

Applying the Louvain algorithm yields a partition of the network into communities (see Fig. 2). Simple frequency analysis then allows to characterise each community through its more frequent items (keywords, authors, etc...). The significativity  $\sigma$  of the presence of a given item into a community is computed by comparing its frequency  $f$  in the community to its frequency  $f_0$  within the whole database. More precisely, we use the normalized deviation

$$\sigma = \sqrt{N} \frac{f - f_0}{\sqrt{f_0(1 - f_0)}} \quad (2)$$

where  $N$  is the total number of article in the database. The links between two communities  $I$  and  $J$  can also be characterized qualitatively by analyzing their shared references and quantitatively by computing the mean weight  $\omega_{IJ} = \langle \omega_{ij} \rangle_{i \in I, j \in J}$ .

The final step in order to create a representation of the BC communities network is to choose a visualization algorithm. We use the Gephi software (Bastian et al. 2009). Gephi is a intuitive and interactive software allowing, in which force-directed layout algorithms are implemented. These algorithms produce a graph by simulating the dynamics of the network as if it were a physical system (the nodes being charged particles and the edges springs). The simulation is run until the system comes to an equilibrium state.

## Copublication coupling

The data can also be analyzed through more common approaches, such as coauthoring or co-keyword analysis (Börner et al. 2003). For this, a list of all items (authors, keywords, addresses) are taken from the records to obtain the nodes of our maps, whose size are proportional to the number of articles in which they appear. Two nodes (items)  $i$  and  $j$  are linked whenever the number  $n_{ij}$  of articles in which they both appear is non-zero. More specifically, we use weighted links, where the co-occurrence normalized weight is chosen as

$$w_{ij} = \frac{n_{ij}}{\sqrt{n_i n_j}} \quad (3)$$

The visualization step of the produced maps is once again achieved through to Gephi and its force-based layout algorithms.

## Software available

We have developed a “Biblio Toolbox” which allows to draw the different maps presented here. The toolbox needs access to Web of Science database but otherwise relies on OpenSource software. It is available at our website (<http://www.sebastian-grauwin.com/>).

## Gaining perspective on the *ENS de Lyon*

### Statistical analysis

ENS de Lyon gathers a broad spectrum of scientific subjects (Table 1), mostly in the natural sciences as discussed above. The institution has significantly grown over the last 20 years, as shown by its increasing production of papers (Fig. 1). The linear growth of the number of published papers until 2000 is the effect of a combination of growing staff numbers after the move from Paris and the progressive use of the new address. Our data gathers 12,398 distinct authors, among which 952 have authored more than 5 papers. By construction of the database, at least one author of each article is a member of ENS de Lyon but this number also takes into account all the authors of the papers among whom some may not be members of the ENS. ENS de Lyon collaborates with a broad range of institutions of different countries as shown below.

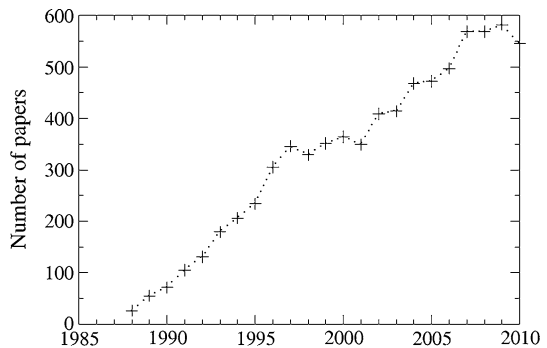
### BC communities map

Figure 2 shows the map obtained with BC of articles and their grouping into “natural” subfields through modularity maximization. Each community is characterized by its most frequent author and keyword. Table 2 displays an “ID card” for the community labelled *Hansen JP/MOLEC-DYNAMICS*. This community gathers physicists interested in the understanding of condensed matter using molecular dynamics simulations. The “ID Cards” of the other communities are available online on <http://www.sebastian-grauwin.com>.

What do we learn from this first map? First, note that the spatial organization of the communities fits well with the scientific organization of ENS de Lyon in different departments (different colors in Fig. 2). This confirms that BC can recover the scientific organization of institutions. Interestingly, the precise community structure does not match

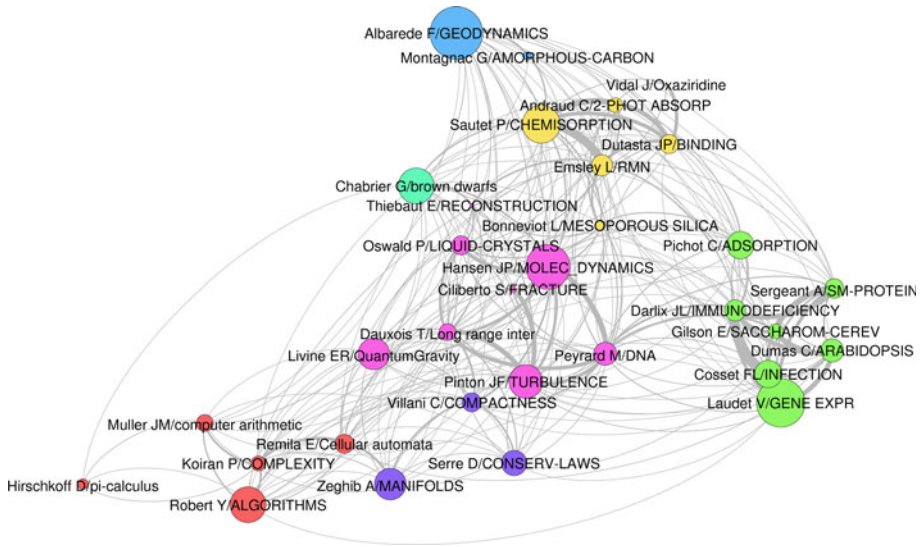
**Table 1** Most frequent *ENS de Lyon*'s subjects

Subject	Prop of articles (%)
Biochemistry and Molecular Biology	8.25
Physics, Multidisciplinary	7.85
Computer Science, Theory and Methods	7.5
Mathematics	7.49
Geochemistry and Geophysics	7.34
Chemistry, Physical	6.41
Physics, Mathematical	6.18
Astronomy and Astrophysics	5.47
Mathematics, Applied	4.73
Cell Biology	4.43
Chemistry, Multidisciplinary	4.34
Physics, Condensed Matter	4.17
Physics, Atomic, Molecular a Chemical	3.9
Physics, Fluids and Plasmas	3.57
Genetics and Heredity	3.23

**Fig. 1** Number of paper with an *ENS de Lyon* address published by year, according to WoS, January 2011

the inner administrative/scientific subdivision of departments. For example, the physics lab is administratively divided into four groups, while our map distinguishes seven teams. This raises interesting questions on the structuration of the groups and their interactions. Two physics' communities (Oswald P/Liquid Crystals and Peyrard M/DNA) belong to the "soft-matter and biological systems" group but our map shows that they are quite distant, which means that they do not share many references. The difference between the map and the physics lab organization is one example of the discussions that our work can generate. In interviews, scientists belonging to these two groups acknowledge that the administrative structuration is somewhat artificial from a scientific point of view. It would be interesting to see how these communities and their relations have been developed over time.

Another example is given by the overall spatial structure. Network visualizations are often interpreted as spatial objects, but spatializations should be interpreted with care since they include additional algorithms and hypothesis. Our map clearly places physics at the scientific center of the ENS de Lyon, a fact that was used by its director to suggest the importance of his lab within the institution. The question is then : how much does this



**Fig. 2** “BC” community structure of the *ENS de Lyon*. The surface of a community  $I$  is proportional to its number of articles  $N_i$  and the width of the link between two communities  $I$  and  $J$  is proportional to the mean BC. For the sake of clarity, communities with less than 10 articles are not displayed. Labels are obtained thanks to a frequency analysis of the authors and keywords. Each color corresponds to one of the ENS de Lyon scientific departments: biology (*green*), chemistry (*yellow*), physics (*pink*), computer science (*red*), mathematics (*violet*), earth sciences (*blue*) and astrophysics (*turquoise*). The belonging of a community to a department is determined through the proportion of community’s articles that use the department (for an example, Table 2 shows that more than 50% of “HansenJP/Molec-Dynamics” articles’ display the Physics Lab in the address). (Color figure online)

central position depend on the precise visualization algorithm used? Is it robust enough to allow for an interpretation and possibly orient governance? The forthcoming maps will comment on this issue, but let us already note that the central position of the Physics Lab *within this representation* is quite robust. The reason is quite simple: the Physics Lab is the only one to have strong links to the other labs. Indeed, different physics’ communities are linked to all other labs (for example Mathematics and Computer science (through Livine E/Quantum gravity), to Biology (through Peyrard M/DNA)...). The other labs are strongly linked only to one or two other labs (for example, Biology is only linked to Chemistry, through Pichot C/Adsorption, in addition to its link with the Physics lab), which explains their more peripheral position in the map. Therefore, the central position of the Physics lab can tentatively be interpreted as its central position in terms of modelling tools (molecular simulations tools shared with chemists for example), experimental tools (on “frictional mechanics” with the geophysics lab for example) or theoretical concepts (spin glass theory also studied by mathematicians). All these shared tools generate common references which lead to the links that structure our map.

### International collaborations

It is straightforward to use the communities of the preceding map to include the international collaborations of the different teams (Fig. 3). We simply define links as given by the frequency of appearance of a foreign country in the community’s articles addresses. For

**Table 2** Community “ID Card”

Institution	Prop	$\sigma$	Authors	Nb authored paper
Ecole Normale Super Lyon	0.766	0.19	Hansen JP	55
Phys Lab	0.543	26.29	Barrat JL	40
CNRS	0.508	1.95	Bocquet L	38
UMR 5672	0.133	10.52	Ciliberto S	38
Univ Lyon	0.111	1.33	Geminard JC	24
Dept Phys	0.076	6.73	Holdsworth PCW	22
Univ Lyon 1	0.075	-3.41	Alastuey A	21
ENS Lyon	0.073	-1.47	Charlaix E	20
Phys Theor Lab	0.073	12.21	Dong W	20
CECAM	0.065	15.67	Cornu F	19
Subject	Prop	$\sigma$	Countries	Nb coll paper
Physics, Multidisciplinary		0.27	France	704
Physics, Mathematical		0.254	USA	89
Physics, Fluids & Plasmas		0.16	Italy	47
Physics, Condensed Matter		0.128	England	37
Physics, Atomic, Molecular & Chemical		0.117	Germany	35
Chemistry, Physical		0.098	Netherlands	25
Materials Science, Multidisciplinary		0.069	Poland	25
Mechanics		0.065	Switzerland	23
Physics, Applied		0.064	Japan	20
Polymer Science		0.042	Chile	15
Keyword	Prop	$\sigma$	Refs	Times used
Dynamics	0.135	14.03	Hansen JP, 1986, Theory Simple Liquid	60
Systems	0.117	13.65	Cugliandolo LF, 1997, Phys Rev E	37
Model	0.104	9.9	Cugliandolo LF, 1993, Phys Rev Lett	34
Molecular-Dynamics	0.053	10.41	Kosterlitz JM, 1973, J Phys C Solid State	25
Behavior	0.043	6.65	Gotze W, 1992, Rep Prog Phys	22
Transition	0.042	6.12	Bouchaud JP, 1998, Spin Glasses Random	22
Fluids	0.04	12.14	Jaeger HM, 1996, Rev Mod Phys	22
Relaxation	0.038	7.27	Alastuey A, 1989, Phys Rev A	21
Flow	0.038	6.96	Frenkel D, 2002, Understanding Mol SI	18
Monte-Carlo	0.036	12.65	Grigera TS, 1999, Phys Rev Lett	18
Journal	Prop	$\sigma$	Refs (journals)	Times used
Physical Review E		0.155	Phys Rev Lett	1709
Physical Review Letters		0.095	J Chem Phys	1406
Journal of Chemical Physics		0.067	Phys Rev B	480
Europhysics Letters		0.058	Phys Rev E	408
Journal of Physics—Condensed Matter		0.043	Phys Rev A	399
Journal of Statistical Physics		0.038	Europhys Lett	353
European Physical Journal B		0.029	Phys Rev E 1	343

**Table 2** continued

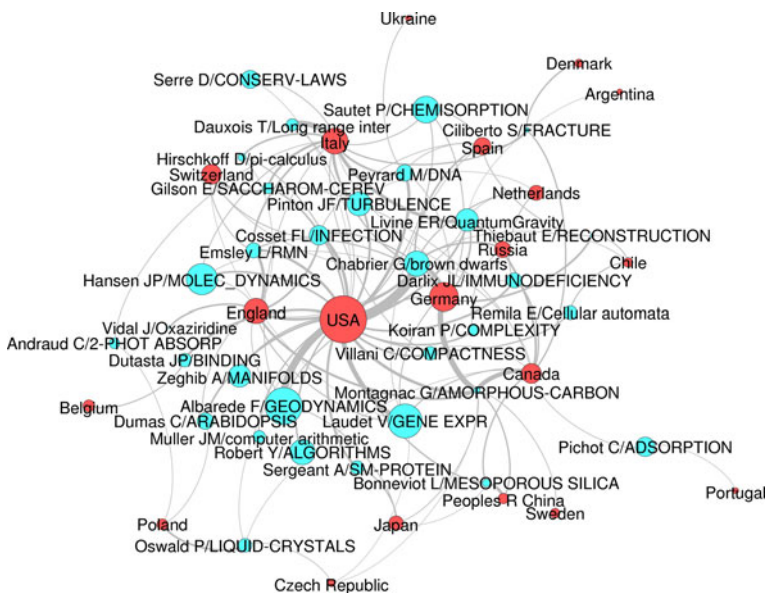
Journal	Prop	$\sigma$	Refs (journals)	Times used
Journal of Statistical Mechanics— Theory and Experiment	0.027	8.39	J Stat Phys	310
Physical Review B	0.023	2.1	Nature	286
Journal of Physical Chemistry B	0.021	4.36	Physica A	276

The community *Hansen JP/MOLEC-DYNAMICS* contains  $N = 547$  articles. Its average internal link weight is  $\langle \omega_{in} \rangle \simeq 1/223$  (roughly, two random articles within the community share 1 reference over 223)

example, the strongest link is obtained for the Astrophysics papers, for which 41% of the papers are written in collaboration with a USA institution. The map shows that some groups rely heavily on many international collaborations (Emsley L/RMN has strong links with England, Italy and USA), while others are strongly linked to a single country (Dauxois T/Long range inter, to Italy) and others have mainly French collaborations (Oswald P/Liquid crystals).

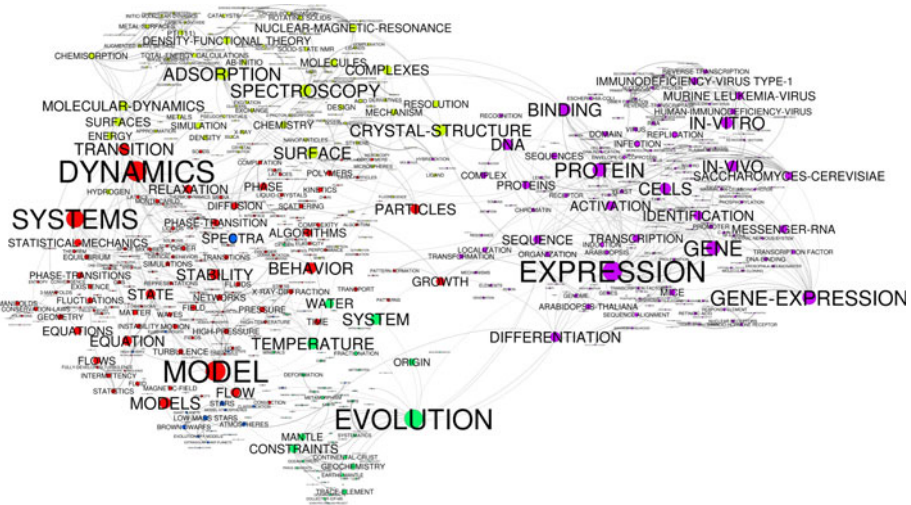
### Co-keywords, co-authors and heterogeneous maps

We now turn to more traditional maps, obtained by co-occurrence of keywords or authors in articles. Figure 4 shows the co-keywords map obtained by using Web of Science and authors' keywords. One should be cautious since some terms are clearly polysemic (“evolution”, “particles”...) and create links between subdisciplines which are not very relevant. However, it is clear that physics is no longer at the center of the map. Instead,



**Fig. 3** International collaborations of the communities. The size of the nodes correspond to the number of articles in each community which imply a collaboration with a foreign country. We only keep countries appearing in more than 10 articles and links corresponding to more than 3% of the articles implying a collaboration with the linked country. The width of the links is proportional to the proportion of linked articles





**Fig. 4** Co-keywords Network. The size of the nodes is proportional to the number of times a keyword is used in our database. The width of the links indicates the cooccurrence weight between two keywords in the same article. We keep only keywords used in more than 10 publications. Colors correspond to a community analysis performed by Gephi based on the same Louvain algorithm used for the BC analysis. (Color figure online)

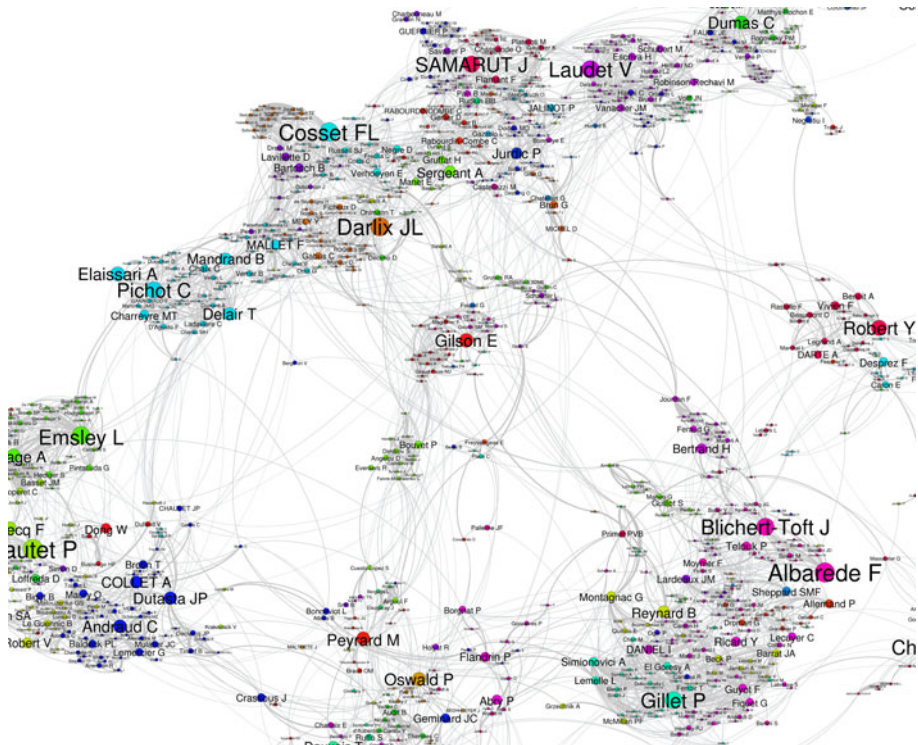
“crystal-structure” links chemistry (top left) with biology (right), “growth” links biology to physics and “transition” and “dynamics” link chemistry to physics (left). Another significant difference : what appeared to be a coherent whole when investigated through BC (the “Albarede F/Geodynamics” community) turns out to split into geochemistry (bottom of Fig. 4) and geophysics (just up of the latter, close to physics, with keywords as “high-temperatures” or “high-pressures”).

Figure 5 displays a co-author map. This represents an accessible way of showing data to the institutions’ scientists, since names are usually well-known by the community. It also represents a good way to tap into directors’ previous knowledge of the institution. However, coauthorship indicates quite a different (and stronger) link from the link established by sharing references (as in BC). This is visible in Fig. 5 which does not show many links across disciplines (and some of the links are actually homonyms, such as Bertin E). The main co-publication link arises from collaborations between a biophysics lab and computer simulations of biological molecules (Peyrard/Bouvet/Gilson).

To improve over the limitations of both co-keyword and co-author analysis and gather most of the available information in a single map, it is possible to include all the co-occurrences between keywords, authors and institutions. Figure 6 shows the map obtained for the ENS de Lyon. It displays the connecting role of a physics-biology interdisciplinary lab (Lab Joliot Curie, center right). One can also see that, while the CNRS plays an important central role, other institutions collaborate on more specialized subfields (for example Univ California, Berkeley, lower left).

## Discussion, conclusions

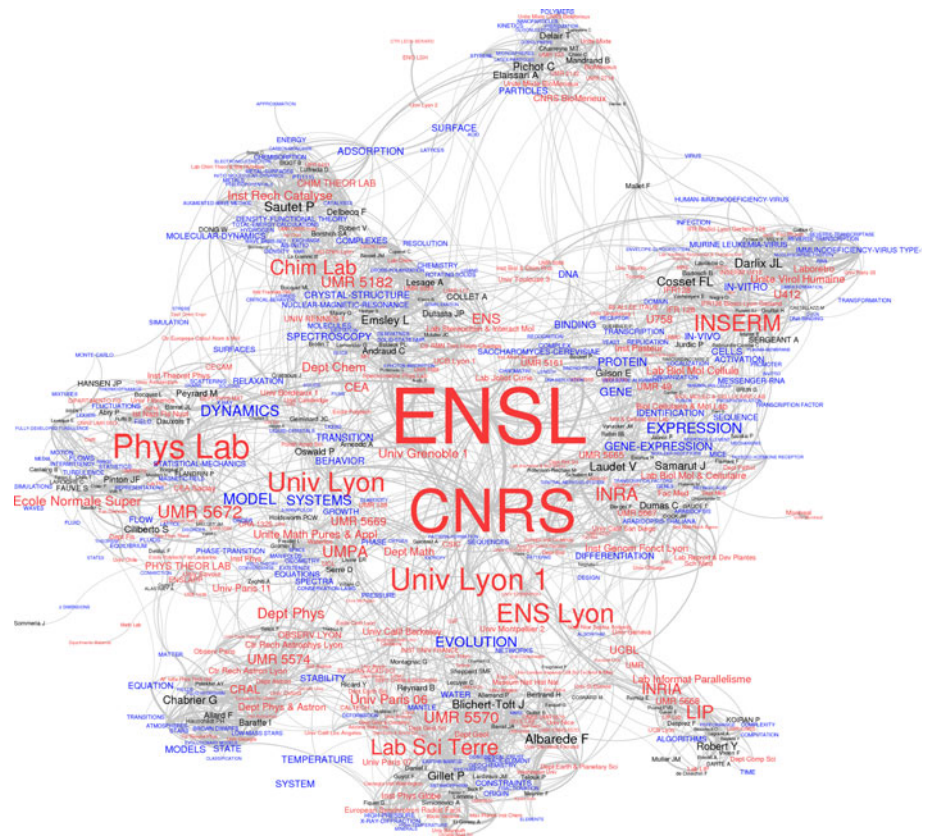
Our aim in this paper was to present a toolbox to map institutions and to show on the example of our institution, ENS de Lyon, what kind of insights can be derived from these



**Fig. 5** Co-authors network (detail). The size of the nodes is proportional to the number of articles of our database authored by the author. The width of the links indicates the cooccurrence weight between two co-authors. We keep only authors used with more than five publications. Colors correspond to a community analysis performed by Gephi based on the same Louvain algorithm we used for the BC analysis. (Color figure online)

maps. It should be clear by now that there is not a unique (or a “best”) map of a scientific institutions, but rather many possible representations, each map containing a projection from a specific perspective (Leydesdorff and Rafols 2009; Roessner 2000; Stirling 2008). An important advantage of using maps derived from BC over tools such as “overlay maps” (Rafols and Leydesdorff 2010) is that our approach defines in a more specific way what are the relevant scientific communities for this organization instead of using a single subject category division derived at the world scale and probably unadapted to most institutions. This allows to have a more precise view on the institution scientific organization, with insights such as the central position of physics or the relative disconnection between teams which are grouped from an institutional point of view (see the discussion in “BC communities map”).

We are now experimenting with ENS scientists’ and direction. ENS heads are enthusiastic about this global vision and five posters representing this papers’ figures are now displayed in the building. We hope that scientists at ENS de Lyon will test these maps against their own knowledge of the institution, will argue with us when what we picture does not fit and join the public discussion by offering alternative interpretations. As Nietzsche said (1969): “the more affects we allow to speak about one thing, the more eyes, different eyes, we can use to observe one thing, the more complete will our ‘concept’ of



**Fig. 6** Heterogeneous network, mixing authors, keywords and institutions. The size of the labels is proportional to the number of articles of our database in which an item appear (we keep only items used in more than 20 publications). The width of the links indicates the cooccurrence weight between two items (we kept only links with a co-occurrence weight  $w > 0.1$ ). Colors correspond to the type of the items (authors in black, keywords in blue and institutions in red). (Color figure online)

this thing, our ‘objectivity’ be’. The point is that although everybody acknowledges that maps are only representations and not the real thing, maps affect how we think about the institution (Wood and Fels 2008).

We hope that our toolbox will lead other scientists to build maps of their own institutions, thus fostering ongoing dialogue and praxis in the institution. Future work includes preparing different maps for successive time periods, in order to grasp the evolution of the institution, and collaboration with other institutions (such as CNRS and CEMAGREF) which are interested in such global maps.

## References

Agarwal, P., & Skupin, A. (Eds.) (2008). *Self-organising maps: Applications in geographic information science*. Chichester: Wiley.

Bastian, M., Heymann, S., & Jacomy, M. (2009). *Gephi: An open source software for exploring and manipulating networks*. Proc 3rd Intl ICWSM Conf.

- Blondel, V. D., Guillaume, J.-L., Lambiotte, R., & Lefebvre, E. (2008). Fast unfolding of communities in large networks. *Journal of Statistical Mechanics*, P10008.
- Börner, K. (2010). *Atlas of science: visualizing what we know*. Cambridge, MA: MIT Press
- Börner, K., & Schamhorst, A. (2009). Visual conceptualizations and models of science. *Journal of Informetrics*, 3, 161–172.
- Börner, K., Chen, Ch., & Boyack, K. (2003). Visualizing knowledge domains. *Annual Review of Information Science and Technology*, 37, 179–255.
- Cambrosio, A., Keating, P., Mercier, S., Lewison, G., & Mogoutov, A. (2006). Mapping the emergence and development of translational cancer research. *European Journal of Cancer*, 42, 3140–3148.
- Chavalarias, D., & Cointet, J.-P. (2009). The reconstruction of science phylogeny, arXiv:0904.3154v3.
- Cobo, M. J., López-Herrera, A. G., Herrera-Viedma, E., & Herrera, F. (2011). Science mapping software tools: Review, analysis, and cooperative study among tools. *Journal of the American Society for Information Science Technology*, 62, 1382–1402.
- Fortunato, S., & Barthélemy, M. (2007). Resolution limit in community detection. *Proceedings of the National Academy of Science of United States of America*, 104, 36–41.
- Girvan, M., & Newman, M. E. J. (2004). Finding and evaluating community structure in networks. *Phys Rev E*, 69, 026113.
- Glänzel, W. (2003). Bibliometrics as a research field: A course on theory and application of bibliometric indicators. [http://nsdl.niscair.res.in/bitstream/123456789/968/1/Bib\\_Module\\_KUL.pd](http://nsdl.niscair.res.in/bitstream/123456789/968/1/Bib_Module_KUL.pd).
- Kessler, M. M. (1963). Bibliographic coupling between scientific papers. *American Documentation*, 24, 123–131.
- Klavans, R., & Boyack, K. W. (2009). Toward a consensus map of science. *Journal of American Society of Information Science and Technology*, 60(3), 455–476.
- Leydesdorff, L., & Persson, O. (2010). Mapping the geography of science: Distribution patterns and networks of relations among cities and institutes. *Journal of the American Society for Information Science & Technology*, 61(8), 1622–1634.
- Leydesdorff, L., & Rafols, I. (2009). A global map of science based on the ISI subject categories. *Journal of the American Society for Information Science Technology*, 60(2), 348–362.
- Nietzsche, F. (1969). *On the genealogy of morals*. New York: Vintage Books (cited by Flyvbjerg B, Making social science matter. Cambridge University Press).
- Noyons, E. C. M. (2004). Science maps within a science policy context. In: H. F. Moed, W. Glanzel, & U. Schmoch (Eds.), *Handbook of quantitative science and technology research, the use of publication and patent statistics in studies of ST systems* (pp. 237–256). Dordrecht: Kluwer Academic publishers.
- Rafols, I., & Leydesdorff, L. (2010). Science overlay maps: A new tool for research policy and library management. *Journal of the American Society for Information Science Technology*, 61(9), 1871–1887.
- Roessner, D. (2000). Quantitative and qualitative methods and measures in the evaluation of research. *Research Evaluation*, 9(2), 125–132.
- Small, H. (1973). Co-citation in the scientific literature: A new measure of the relationship between two documents. *Journal of the American Society for Information Science*, 24, 265–269.
- Small, H. (1999). Visualizing science by citation mapping. *Journal of American Society of Information Science*, 50(9), 799–813.
- Stirling, A. (2008). “Opening up” and “Closing down”: Power, participation, and pluralism in the social appraisal of technology. *Science, Technology and Human Values*, 33(2), 262–294.
- Wood, D., & Fels, J. (2008). *The natures of maps: Cartographic constructions of the natural world*. Chicago, IL: University of Chicago Press.