Visual Analytics of Bibliographical Data for Strategic Decision Support of University Leaders: A Design Study

Paul Rosenthal[1], Nicholas H. Müller[2] and Fabian Bolte[3]

[1]*Institute of Computer Science, University of Rostock, Rostock, Germany*

[2]*Faculty of Computer Science and Business Information Systems, University of Applied Sciences Würzburg-Schweinfurt, Würzburg, Germany*

[3]*Department of Informatics, University of Bergen, Bergen, Norway*

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Abstract: As responsibilities about documentation of work in conjunction with an increase in third-party-funding for universities have been shifting over the last decade, new tools for the inspection and reporting of data are increasingly requested for strategic decision making. Therefore, we present a design study that aims to craft a stream visualization for the easy to use and easy to understand display of publications across university institutions. A formal design process was performed and led to a web-based visualization prototype of the available university data sets. The used visualization techniques, counting methodology, highlighting practices, and interaction paradigms are discussed and presented in detail. The design study was completed by an informal evaluation procedure within the ranks of strategic decision making staff. It turned out, that the developed expert tool allows to identify connections for future projects. In addition, it enables management to recognize promising departments or to apply support where it is needed.

1 INTRODUCTION

The societal role of universities as institutions to gather and distribute knowledge has begun to change over the last decade. Whereas scientific research is still a very relevant attribute, the importance of monetary funding has increased dramatically. Stating this, also the role of publications in academia is about to change from a method of communication and recognition into an instrument of academic steering for the measurement of academic success. In addition, a promising publication record is not just relevant for tenured professors but it is increasingly becoming relevant as an entry-criteria into academia in general (Riegraf, 2018).

Although this has been true for decades already, the questions of university decision makers have become much more complex. At the beginning, it was sufficient to count publications or probably distinguish between monographs, journal articles, and contributions to proceedings. Nowadays, questions include much more complex dimensions. Here, it typically not only suffices to include impact measurements of the publication venue but also university-specific dimensions have to be considered, like an interdisciplinary set of authors or the inclusion of external authors.

Compared to financial data and independent from the scientific discipline, publications are usually the best maintained parts of any department's website, getting refreshed as soon as the contribution is published. In addition, these numbers are in most cases also available in a multitude of public repositories like Google Scholar or other discipline-specific derivatives.This does not only allow for an adequate assessment of the raw publication potential, but also indicates ongoing and developing connections across interdisciplinary boundaries. By assessing the authors of the publications, any university administration could easily identify connections to other universities, countries, or even connections to industry partners. An easy to use, easy to interpret visualization of these aspects when looking at publication data, could be key to generate new cooperations.

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2 USE CASE

In the following, we present a design study that specifically deals with this general challenge and introduces an easy to use solution for a practical use case. The work has emerged as part of the strategic readjustment of a medium-sized university of about 10,000 students and around 2,000 staff members in relation to the ongoing challenges of academic politics in Germany. The respective university consists of eight faculties with nearly 200 research departments.

In order to maintain viable information about publications, the university's library runs an internal data base of all university publications. To update this list of publications is mandatory for all departments and is being collected since 2008. The collection currently consists of significantly more than 20,000 publications. For each publication, the following relevant data are collected:

- title
- author names and affiliation
- type of publication
- name of journal, book, or proceedings
- year of publication.

The data base is supported by an ontology of the university bodies, structuring the authors and research groups to the different institutes and departments. Here it is important to note, that research groups may belong to several institutes or even two or more departments.

Since such data is collected in a majority of universities around the world and similar questions regarding the importance of publications arise, the tackled use case and the further considerations can be generalized. This is even true for use cases outside academia, where a holistic overview over publications data is needed for steering strategic decisions.

Main stakeholders in our tackled use case are the university's strategic deciders, specifically the president, the vice presidents, the deans, and the managing employees. The main objective of the project was to develop a prototype with the following communicated features:

- It relies on the internally collected bibliographic data and the incorporated university structure.
- The prototype provides an instant visual output and allows for intuitive interaction through non computer specialists.
- University's decision makers can utilize the prototype to gain operational insights and support strategic decisions.
- The prototype should be implemented as a web service with minimal requirements and can easily be transferred in the future into a service parallel to the web-based bibliographic data base.

3 REQUIREMENTS ANALYSIS

Relying on the aforementioned project definition, a team of three researchers began the design study by analyzing the design requirements. The team consisted of a senior researcher in media psychology, a senior researcher with background in requirements analysis and visual analytics design, and a junior researcher in the field of interactive visualization and data processing.

In a first phase, a group of six permanent contact persons, representing all relevant stakeholders, was recruited and agreed to support the project throughout the different phases. The members of this core-user group were individually interviewed on how to interpret the project objectives in a semi-structured way. Our main goal of this approach was to extract the key features, the users wanted to inspect, how these relate to each other, and how these contribute to the strategic decisions. Additionally, key features of the future prototype and show stoppers had to be identified.

In summary it turned out, that the core users had the following very similar requirements:

R1: Besides the pure number of publications, users need to inspect fractions of certain types (journal article, book,. . .) of publications.

R2: Users need to quantify the publications with respect to interdisciplinarity and involvement of external partners.

R3: The users need to quantify the publication data in development over the time dimension.

R4: The users need to compare all data with respect to the university structure (departments, institutes, research groups).

R5: The tool, its navigation, and all used visual encodings need to be intuitively understandable for the core users without any form of instruction manual or a training period.

4 STATE OF THE ART

Professionally establishing their own bibliographic data base is not a new approach for universities. Still, this is not common for most academic institutions. Even less common is the strategic analysis of such data for the long-term steering of resources - a novel idea for the academic institution we chose for our applied research. Instead, most of the time the publication data is merely used as a pledge in financial negotiations with the state.

Informal and non-representative investigations among international university decision makers have revealed that this is also true for many other universities. If such bibliographic data bases exist and a strategic analysis is desired, universities currently have to rely on standard tools since no specialized visualization software is readily available. In most cases, this is done by manual analysis, using tools ranging from pure spreadsheets to sophisticated visualization suites. Although these tools offer a wide range of feature richness, their common drawback is that they are not made for the instantaneous usage by novices. Even visualization experts are often initially overwhelmed by the huge amount of visualization possibilities, making a spontaneous inspection session with deciders impossible.

5 RELATED WORK

Nowadays, there exist plenty of general collections of bibliographic data. Even topic-specific and curated collections, like Vispubdata.org for the IEEE Visualization publications (Isenberg et al., 2017), rise more and more. In addition, the analysis of such data collections gets increasingly more comfortable with the growing number of analysis tools, like for example SurVis (Beck et al., 2016).

Apart from such general-purpose techniques, many different approaches have been presented for specific use cases. For example, Van Eck and Waltmann (van Eck and Waltman, 2014b; van Eck and Waltman, 2014a) visualize bibliometric networks on the author level. Although the presented CitNetExplorer allows for detailed inspection of author connections, it seems to be not so easy to incorporate the special meta structures of universities and answer the relevant questions. This also applies to several other graph-based approaches for visualizing bibliometric data (Bornmann and Haunschild, 2016; Brandes and Pich, 2011; Newman, 2004; Sallaberry et al., 2016).

On the meta level, Fung et al. (Fung et al., 2016) investigate the effectiveness of three different bibliographic network visualization techniques and reveal the weaknesses and strengths of node-link diagrams, adjacency matrices, as well as botanical tree visualizations. This work concentrates on the individual development of each researcher, including the individual publication network. Comparisons between several different researchers are hard to obtain.

Concentrating more on the chronological aspect, Heimerl et al. (Heimerl et al., 2016) visualize publications in a stream graph. The presented visualization is enriched by an excerpt of the content and detailed bibliographical information. Similarly, Jänicke et al. (Jänicke et al., 2016) visualize specific data of the life of musicians. The authors incorporate several additional dimensions like life events, connections, or confession into a stream graph.

On the other hand, Wu et al. (Wu et al., 2013) present a novel visualization technique for analyzing the individual career paths of academic persons. The visualization includes a stream graph representation of the publications, superimposed with specific events in the respective scientific path ways. Following these lines, Wang et al. (Wang et al., 2018) present the tool ImpactVis to visualize the impact of researchers through bibliographic data. The authors concentrate on the in-depth analysis of the individual literature records of researchers and their detailed citation connections to other researchers.

In consequence, this development of new visualization techniques has also brought up a huge amount of literature surveys. For example, Mascarenhas et al. (Mascarenhas et al., 2018) perform an extensive literature review on university-industry cooperations and their effectiveness for promoting innovation in industry and research.

Comprehensive surveys over the field of visualizing bibliographic data were recently presented by Liu et al. (Liu et al., 2018) and Federico et al. (Federico et al., 2017). Although there are many interesting ideas to help with the challenges of our tackled use case, none of the presented approaches is out-of-the-box suited for fulfilling the compiled requirements.

6 DESIGN PROCESS

Since none of the inspected related approaches or existing tools was matching the design criteria, the design of a new expert tool was desired. As proof of concept, the development of the prototype was pursued on basis of a dump of the original data base for the time period 2009–2014.

6.1 Data Preprocessing

Initially, the existing data was investigated in terms of data quality. It turned out, that also a professionally maintained data set contained the same problems which all manually entered data sets have. Most of the problems could be broken down to missing or incorrect values as well as spelling errors. As a preprocessing step for this design study, all singular or oddly appearing values were manually inspected and, if needed, corrected by inspecting the publication. Also, duplicates were semi-automatically discovered and manually removed from the pool.

On basis of the, now reliably "cleaned", data set, it was time to investigate whether or not all the requirements from Section 3 could be reliably backed by data. The requirement R1 should be easy to obtain, since the needed data is directly included in the data set. This also applies to R3 and R4. Since R5 forms no requirement in terms of the data, it also has no consequences for the preprocessing step. In terms of R2, some preprocessing was involved to obtain the needed data. In an automated process, all authors of each publication were categorized with respect to the university structure. Afterwards, a publication was additionally marked in the following way as:

institute internal, if only authors from the same institute contributed to the publication.

department internal, if all authors of the publication belong to the same department, but at least two different institutes are involved.

interdisciplinary, if authors of at least two different departments are involved but no external authors.

external, if the publication features at least one external author.

For the strategic thoughts of the investigated core users, this intersection-free partition was important and explicitly desired. However, this can differ if other focus points are tackled in the related use cases. It is also important to note, that in the structure of the investigated university, research groups may belong to different institutes or even two or more departments. With respect to this structural feature, publications were for example marked as interdisciplinary if authors from at least two research groups were involved and one research group belonged to at least one department the other research group did not belong to.

6.2 General Procedure

In general, the user-centered part of the design study was performed in an iterative fashion on basis of rapid prototyping. The six members of the stakeholder group were initially confronted with simple sketches of design ideas. Feedback was steadily integrated into the development of new prototypes, leading to a flow of artifacts with increasing complexity, functionality, and closeness to the practical working prototype.

Although the communication with the users was mainly based on digital artifacts, initial sketches were done with pen and paper in sketching sessions (Greenberg et al., 2011; Walny et al., 2015), allowing for more freedom and creativity. This changed over time for more preciseness to digital pictures and pseudo-animations. In the late iterations, web-based mock-ups and prototypes were used, implemented on basis of Data-driven Documents (D3) (Bostock et al., 2011), as also the final prototype.

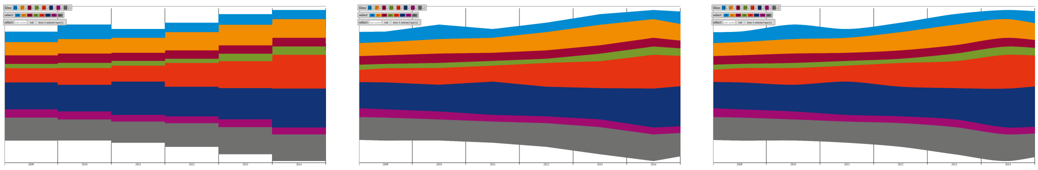
6.3 Layout

All experts agreed that the final tool should rely on keyboard and mouse as interaction mechanisms and should use standard monitors as display devices (R5). Still, we also tried to keep in mind mobile friendliness, should future requirements arise in this direction. However, this also heavily influenced our decision for a standard two-dimensional and rectangular layout of the desired design.

Since the two main dimensions for nearly all practical questions and usage scenarios are the number of publications and the time dimension (R3), these two also emerged in the design process as dimensions to map to the two-dimensional design space. Having fixed this setting, there still do exist many different visualization methods for time-oriented discrete data. A survey was recently presented by Brehmer et al. (Brehmer et al., 2017). However, after very short discussion it was clear, that the optimal setting was to put the time dimension from left to right, the natural dextrograde process flow for Europeans, and the number of publications to the vertical axis.

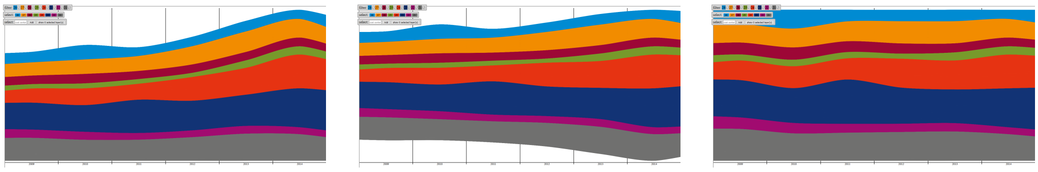
This design decision and a thorough review of visualization methods for time-oriented data (Aigner et al., 2007; Aigner et al., 2011) let to the concept of visualizing the amount of publications in a stream graph (R1, R3), as proposed by Havre et al. (Havre et al., 2000; Byron and Wattenberg, 2008). With this concept there are at least two additional degrees of freedom involved, the type of interpolation between the discrete years and the the interpolation with respect to the publications axis. Interpolating the time axis is basically trading accuracy for visual appeal. A comparison of the three supported approaches (constant, linear, and polygonal interpolation) is presented in Figure 1. Since none of the approaches is optimal for all different usage scenarios, the prototype allows for switching between them, with polygonal interpolation being the default setting.

Also for visualizing the publications axis, there are several different possibilities, from which we have identified three possibilities that have their eligibility



Constant Interpolation Linear Interpolation Polygonal Interpolation

Figure 1: Different types of interpolation between the number of publications per year. While the constant interpolation gives the most correct representation of the discrete data set, the polygonal interpolation produces the most pleasing visualization. In most cases, the linear interpolation was favored as a good balance between both extrema.



Bottom Baseline Centered Baseline Filled Space

Figure 2: Different types of visual indication of the number of publications.

for the different questions to answer. Figure 2 shows the three different types. Putting the baseline at the bottom of the screen and scaling the number of publications constantly over the years allows for the most precise judgment of the overall number of publications and its development. In contrast, centering the number of publications for each year at the middle of the screen, minimizes distortions of the boundary streams and makes inspection of individual streams easier. From our core users this visualization was also rated the most pleasing and in most cases useful. Consequently, it was set as the default representation. When only questions of relative comparisons over the years have to be answered, it is also possible to stretch the whole set of publications per year over the full design space, resulting in a relative stream graph.

6.4 Colors

Apart from the placement in space, color and brightness denote the most visible visual cues in a visualization. Consequently, the discussion of colors was a long phase of the design process. Although there are several surveys on the different color maps and their special features (Silva et al., 2011; Zhou and Hansen, 2016), it was very hard to profit from these insights in terms of our use case. As part of the university's corporate identity, all departments were given individual and specifically defined colors. So it was not unexpected when all deciders unanimously agreed that these colors had to be used throughout the whole visualization for publications belonging to the respective departments (R4).

Under these restrictions, the only color features left to change and use for other visualization purposes were the saturation and transparency. Since it was stated that saturation should, again thanks to corporate identity, only be changed in small portions, we chose to use this visual cue to deduct different research groups or institutions within a department from each other. An example visualization is shown in Figure 3.

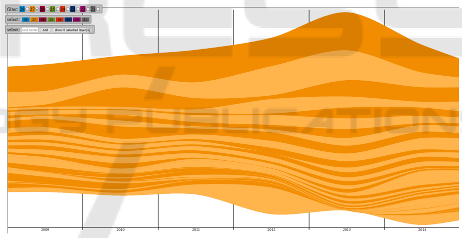


Figure 3: Using alternating saturation for indicating the different research groups of a department.

Changing transparency on the other hand gives the chance of encoding continuous values in addition to the already provided time dimension and number of publications. This is a feature, the core users very much liked in our feedback rounds. In our design, we provide the possibility to encode all different fractions, like the fraction of interdisciplinary papers, to the transparency value of each stream (R1). This gives the user an instant relativization of the number of publications, as illustrated in Figure 4.

All other visual encodings like additional symbols, hatching, shadows, or three-dimensional effects were refused by the core users as too complicated, too cluttering, or not being self-explanatory enough.

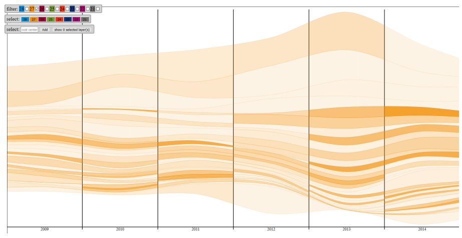


Figure 4: Mapping a third value, ideally a fraction percentage to the transparency, allows for generating insights just within one glance.

6.5 Counting

In terms of the different color codings, one challenge came into play, which is often occurring if data is not uniquely assignable. Each publication may include several and a different number of authors, institutes, or departments. Consequently, the question arises how to count this one publication with respect to the different structural entities. This aspect is discussed in great detail by Perianes-Rodriguez et al. (Perianes-Rodriguez et al., 2016).

After long discussions of strategic goals and their match to this question, the users decided to count each publication once per author, such that a publication with six university authors is represented six times in the visualization. This procedure specifically promotes publications with multiple authors, postulating that all authors also really contributed to the publication. In addition, the fractions of external authors were added to the parts of the university authors to not penalize such publications.

In terms of institutes and departments, the same strategy was applied. If a publication has two authors from one department and three from another one, the departments got the respective share of two and three publication counts. In the case of research groups belonging to multiple structural organizations, these contributions were equally split among the departments or institutes.

6.6 Interaction

The last very important step in our design process was the interaction. An early inclusion of interaction into the design process was achieved by constructing fake interactions already on the pen-and-paper level. Having said this, most of the desired interactions were already defined at very early stages of the design process. Since the core users were very conservative interface users and the final tool had to be very intuitive (R5), the interaction possibilities turned out to be quite conservative as well.

As first interaction method, the movement and zooming of the visualization is operated by the well-known mouse operation (click and move, moving the mouse wheel). An even more important feature was the possibility for detailed inspection and exploration of the data. This was ensured with a mouse-over functionality of the prototype. Once the mouse is hovering over a research group at a specific point in time, all available data is indicated in a tool tip, as illustrated in Figure 5. In addition, the respective stream of the research group is highlighted in the stream graph (R3). Switching the different modes of coloring and superimposing the data with characteristic fractions was implemented using simple menus with descriptive symbols and text.

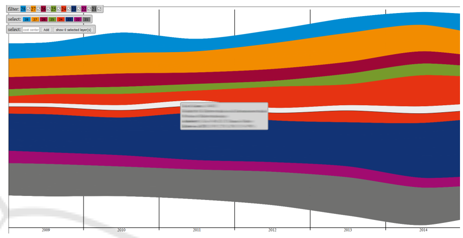


Figure 5: The presented tool features a mouse-over effect. For each research group the mouse pointer is currently over, all available data at the respective point in time is indicated in a tool tip and the stream of this research group is highlighted in the visualization.

Another, but also very important feature for the core users, was the ability to interactively sort and filter the data (R1). For this interaction function, different interaction techniques were desired and implemented. Clicking at specific streams in the visualization selects or deselects them. An interactive list shows the IDs of the currently selected research groups. In addition, a selection or deselection is also possible by manually entering the IDs. This feature was specifically asked by the deans who know their department IDs very well. However, also in the university administration this feature was rated as being very handy if a speedy analysis of a specific university consortium is desired. Once the selection is final, the visualization can be filtered down to the selection by pressing the ENTER-key or the right mouse button. An illustration of the filtering is shown in Figure 6. The same keys also switch off the filter again. Clicking on empty screen space or hitting the ESC-key clears the current filter list.

Regarding the filtering, it was also explicitly desired to implement short cuts for the most important filters, like the departments. These are implemented as buttons in the top left corner of the tool and allow for instant filtering of a set of departments or the instant selection of the research groups of whole de-

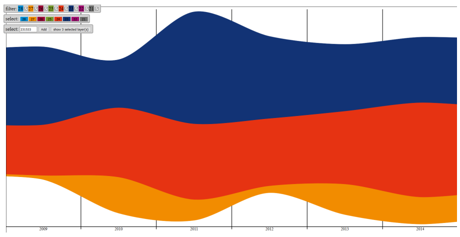


Figure 6: The presented tool features the filtering up to individual research groups. In the shown visualization, three research groups from different departments were selected.

partments. Using an additional click at the top of the respective time column it is also possible to sort the currently visible streams with respect to the absolute number of publications in this year. An illustration of this feature is given in Figure 7.

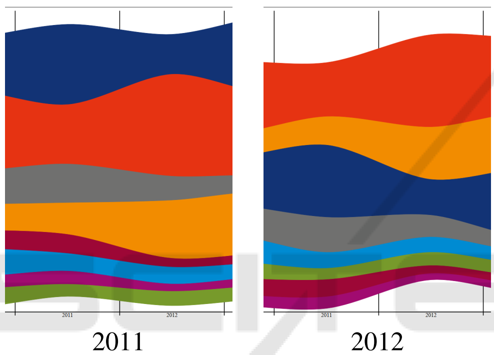


Figure 7: Illustration of the sorting feature. Clicking the column of a specific year, allows to sort the visible streams with respect to the number of publications in this year.

As keyboard and mouse interaction might in the future be replaced by other techniques, it was important to keep the chosen metaphors as open as possible. In the specific case it is clear that a switch to a touch interface would be instantly possible without major changes to the interaction concept.

7 EVALUATION

The following describes our preliminary evaluation of the visualization prototype for detailed publication data inspection across faculties and departments. We used the aforementioned method of visualized publications to allow for a detailed inspection with one German university and discussed the outcome with different departments and the general university administration. Since third-party funding is getting more important to keep universities afloat, the general feedback to our publication overview during our ongoing informal interviews is that of great interest in the various methods of visual analysis.

Especially in the case of decision making and strategic guidance, the comparison of different aspects of the publication data allowed for a more intuitive and reliable interpretation of which department would benefit from strategic intervention in the case of producing research requests or to acquire other forms of project funding. Since many insights are closely coupled to additional data and have to be seen in much broader context, it was hard to extract descriptive examples.

One very impressive example was given by a dean during the evaluation sessions. The dean discovered during the interaction sessions just on his own the visualization depicted in Figure 8. Having this comparison of all research groups over time with total number of publications and additional encoding of interdisciplinarity of the publication enabled him to generate an in-depth insight into the publication behavior of his department at a single glance.

During the evaluation phase, there were several other of these light-bulb moments among all participating deciders. In addition it was observed, that the display of external publications provides a novel form of easily and readily being able to identify persons to contact in the case of other research and development projects. In summary, they all agreed that the prototype allowed for insights that were previously barely possible or just with significant extra efforts. In consequence, the project was recommended to be further pursued and developed to a usable standard tool.

8 CONCLUSIONS

In this design study, we have analyzed the use case of visualizing bibliographic data to support university decision makers. The use case was researched in detail, following a rigorous requirements analysis. A visualization design on basis of the requirements was created in an iterative process, resulting in a new form of visualization for publications at universities. Compared to only analyzing financial data, the constructed interactive tool gives valuable additional insights and allows for in-depth inspection through decision makers. This leads to new opportunities for strategic decision-making at universities, since interdisciplinary work as well as internal and external research connections are readily available and easy to identify when using our tool. This fact was confirmed by an informal user study with real expert users.

The findings of the requirements analysis, the design process and the evaluation can be generalized to other similar use cases. At the moment, our visualiza-

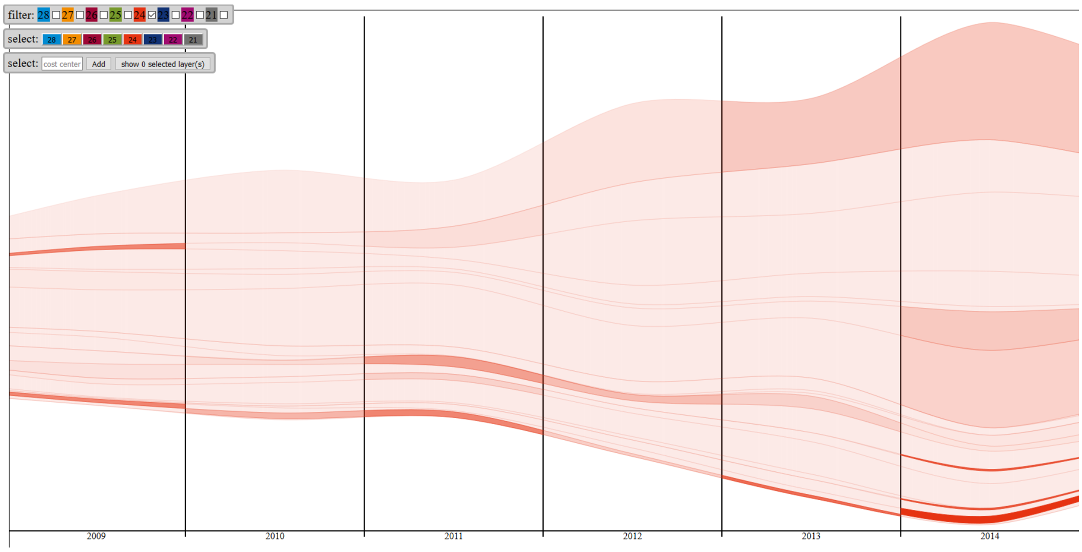


Figure 8: Visualization of all research groups of one individual department. For each research group, the transparency is chosen to represent the fraction of interdisciplinary papers.

tion is based on internal publication data. However, due to its ability to rework many other forms of input data, it can be easily extended to other sources of literature repositories. Furthermore, an additional layer of significance could be added by integrating impact factors, publication venues, and other dimensions into the representation.

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