Personometrics: Mapping and Visualizing Communication Patterns in R&D Projects

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Abstract. People such as R&D engineers rely on communication with their colleagues to acquire information, get trusted opinion, and as impetus for creative discourse. This study investigates the prospects of using bibliometric citation techniques for mapping and visualizing data about the oral communication patterns of a group of R&D engineers. Representatives of the R&D engineers find the resulting maps – we term them personometric maps – rich in information about who knows what and potentially useful as tools for finding people with specific competences. Maps of old projects are seen as particularly useful because old projects are important entry points in searches for information and the maps retain information indicative of people's competences, information that is otherwise not readily available. Face-to-face communications and communications via phone, email, and other systems are more ephemeral than scholarly citations, and (semi-)automated means of data collection are critical to practical application of personometric analyses.

1 Introduction

Interpersonal communication is of key importance in knowledge-intensive organizations such as those in research and development (R&D). Studies have repeatedly found that engineers rely more on oral communication with organizational colleagues than on written communication such as project documentation, textbooks, and research papers [2, 14, 20]. Conversely, research in Library and Information Science (LIS) has primarily concerned itself with search behaviour related to retrieval of information from documents [8, 24]. Given its practical significance there is an urgent need for additional research on how to represent people as information objects, as a means to assist effective identification of people who are capable of providing information, advice, and trusted opinion. This study investigates the prospects of adapting techniques originally developed for citation analysis to visualizing communication and competence patterns in R&D projects.

Within bibliometrics, authors are related to each other by means of their citation patterns; thereby providing information about the intellectual structure of a domain [4, 22, but see also 16]. There are potentially exciting possibilities for using bibliometric

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techniques in other domains and for other purposes than the study and evaluation of scholarly writing. In this study, we aim to outline how such techniques can be utilized for investigating, mapping, and visualizing the competences of individual employees in organizations, based on the patterns of communication they exhibit in accomplishing their tasks. We term this *personometrics*, a field of study intended to advance our understanding of people as information sources and, thereby, inform the design of people-finding systems.

We conducted an exploratory empirical study in which the participants in an R&D project were asked to indicate the personal communications they engaged in as part of their day-to-day project activities. Data were collected by means of a questionnaire and validated by interviews. If individuals can be viewed as information objects it should be possible to represent project participants visually through mapping. We aim to investigate:

- Whether such maps can be constructed by applying bibliometric citation techniques to data about project participants' interpersonal communication patterns
- How project participants react to these maps and whether they consider them indicative of people's competences and of potential value as a people-finding tool.

We expect that personometric maps will visualize information that is partially tacit and not fully known by some project participants. This way personometric mapping is inscribed in and adds to a collective cognitive perspective on information seeking [12]. Further, personometric mapping entails that users are presented with and considered capable of interpreting fairly large amounts of data (whereas computer power is directed at visualizing the information space). This accords with humans' greater ability to browse and thereby recognize what is wanted over being able to describe it by means of queries.

2 People as Information Sources

With the reference interview as a prominent exception, LIS studies of collaborative aspects of information seeking tend to focus on collaboration among peers – often engineers – and on how technology may enable such collaboration. The most well-known example of collaborative information seeking is probably Allen's [2] description of the gatekeeper phenomenon. A gatekeeper takes the responsibility to look for information and, when consulted by colleagues, forwards it to people in her team or organization. This way, the recipient of the information and the gatekeeper collaborate to find information useful to their work. In relation to this study, the key contribution of the gatekeeper phenomenon is its attention to collaboration and communication because this attention entails that people are recognized as central sources of information. Though many studies have investigated communication among engineers [14, 20], we still lack a solid understanding of what it is that makes people such good information sources. Elements of such an understanding are, however, emerging [9, 10]:

- Engineers are involved in a construction process and for that reason they need a *synthesis* of the prospective product and use situation and are only *analysing the present* as a way of getting at the future. The ability to transcend current practice, identify underlying needs, and envision new products and ways of working is specific to people – though they find it difficult.
- Engineers are involved in an applied process and for that reason they are often looking just as much for *experiences* with certain tools or work tasks as they are looking for *facts*. Such experiences are seldom available in writing because such explication is a difficult and time-consuming activity, because other activities compete for experienced people's time, and because the experienced people themselves gain little from committing their experiences to writing.
- Engineers are involved in a cooperative process and for that reason they often need *commitment* to future actions as much as they need *information*. The capacity to make commitments is specific to people. In many situations the distinction between information and commitment is, in fact, blurred because people thought capable of providing information may instead commit to investigate the issue in question, or vice versa.

In many if not most organizations, few organizational mechanisms are in place to manage the flow of communications among people. A good few prototype systems do, however, attempt to support people in finding other people with specific competences. These include Referral Web [13] which helps find research experts based on co-occurrences of names, Yenta [7] which matches people based on textual analysis of personal profiles, Expertise Browser [17] which uses data from a change-management system for software engineering to locate software engineers with desired knowledge, and Answer Garden [1] which routes users to recorded information, if available, and otherwise to knowledgeable people. Whereas these prototype systems hide the data upon which the systems base their suggestions for people to contact, we explore the prospects of visualizing these data by means of personometric maps.

3 Personometrics

Personometrics is a field of study in which quantifiable data about the relations between individual persons serve as the basis for mapping intellectual structures in an organizational environment. Personometrics is inspired by bibliometrics, in particular scientometrics, which attempts to map the intellectual structures in a domain or discipline by means of citation data [19, 23, 24]. Further, personometrics resembles certain branches of social network analysis [18, 21]. In personometrics, data are collected about the colleagues with whom people communicate when they are in need of information. These data comprise what could be termed *social reference lists* to emphasize that personometrics is based on representations of *persona*, not *biblos*. As we outline it, personometrics is specifically targeted at the actual patterns of communication that ensue in response to employees' information needs. That is, formal organizational structures with nominated specialists are only recognized if the nominated specialists are actually consulted by their colleagues.

The peer communications represented on social reference lists to some extent resemble scholarly citations but also exhibit distinctive characteristics. First, people communicate with their colleagues to acquire and explore a web of information from different domains and therefore familiar to people with different professional backgrounds. Normally, no single R&D engineer knows all the domains involved in an R&D project in the necessary detail. Second, whereas engineers sometimes communicate with their colleagues to get factual information they regularly seek feedback on their ideas or designs, either as trusted opinion or as impetus for creative discourse [25]. Third, engineers' close working relationships with their colleagues often enable them to select the person to approach in a given situation based on such fine details and informal distinctions as the person being very helpful, too slow, or inefficient due to lack of recent experience with this particular topic. Fourth, people frequently combine sources when they look for information and thus intertwine looking for informing documents with looking for informed people [11].

Personometrics borrows from bibliometric methods in which citation data are aggregated into condensed descriptions that acquire robustness from the large amounts of data they bring together as well as from the scientific tradition that scientists cite each other and, thereby, contribute to an inter-subjective qualification of scientific results [23, 24]. With respect to amounts of data, work in organizations abounds in communication among colleagues, providing plenty of data for personometric analyses, see Fig. 1. Previous research suggests that people also communicate with each other in ways that could, over time, be accumulated into inter-subjectively qualified descriptions of their colleagues as information sources [2, 5, 6, 8]. This is, however, a critical precondition for personometric analysis and rather than merely assuming it we address this issue explicitly in our empirical study.

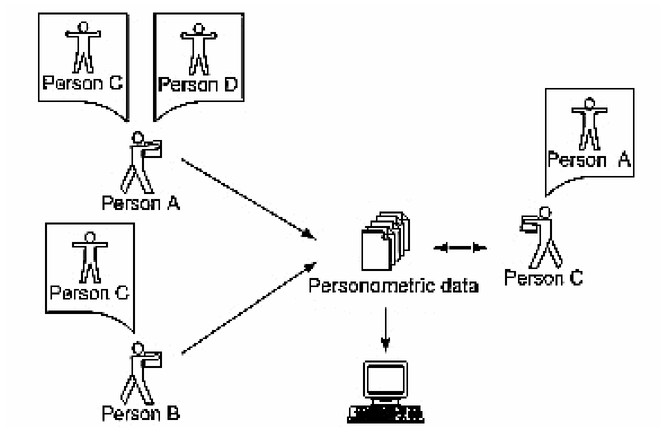

Fig. 1. Collecting data about interpersonal communications for use in personometric analyses

The empirical results presented in this article are based on data collected via questionnaires. Questionnaires are, however, unsuited for real-world applications of personometrics to the design of people-finding systems because questionnaires must be filled in manually and this is a resource-demanding activity that easily gets postponed or glossed over, especially as the questionnaire must be administered regularly to keep the personometric data up to date. Thus, automated means of data collection are needed. Multiple possibilities present themselves, including extraction of sender and recipient information from emails and phone calls, extraction of information about meeting participants from electronic calendars, and extraction of visitor information from employees' web pages [see, e.g., 5, 6]. In addition to information about the parties engaged in communicating it should be noted that email, web sites, and other forms of computer-mediated communication also provide opportunities for extracting keywords describing the topics about which people are consulted.

Data such as sender and recipient information for emails and phone calls are often recorded already, but reusing them for new purposes requires careful consideration of privacy issues. These issues may concern (a) the raw data extracted from, for example, emails and (b) the aggregated data presented to users of the people-finding systems. For the raw data, one approach is to automate both the extraction and the processing of them, and thereby make the raw data invisible to humans [7]. Another approach is to provide each employee with the data that involve him or her and the opportunity to make deletions in these data before they are included in the next update of the people-finding system. The aggregated data presented to users of people-finding systems may vary from detailed personometric maps, such as those in the empirical study below, to none at all. If no aggregated data are presented the system merely suggests people to contact but provides no clues as to the basis of its suggestions. This is the approach adopted by most extant people-finding systems [e.g., 1, 5, 7].

4 Empirical Study

Oticon A/S, which develops, produces, and sells hearing aids and other communication products, has a flat organizational structure, an open office landscape that emphasizes informal communication, and is characterized by self-organizing projects. The project in which our empirical study took place concerned the development of platforms for hearing aids targeted at the low-end segment of the market. The project had 22 participants spread across two sites that were several hundred kilometres apart. The project participants were mainly engineers (in the fields of electro acoustics, integrated circuits, applied digital processing, and quality management) but also audiologists and people from marketing and creative communications. As a self-organizing team the project had its own budget and was to a large extent autonomous, although supported by a set of staff functions. This gave the project group a wide range of contacts with people external to the project group.

4.1 Methods of Data Collection

We collected data from the project at Oticon by means of a questionnaire administered to all project participants and two validation interviews. The purpose of the *questionnaire* was to provide survey data about the informal communication patterns in the project. Apart from general information such as professional group respondents were asked to indicate the persons they communicated with in accomplishing their project tasks. The names of all project participants were listed in the questionnaire to jog the respondents' memory, and empty slots were available for indicating communication with people external to the project. For each person with whom they communicated the respondents were asked three questions:

1. Who typically initiates communications? Categories: you, her/him, or equally split.
2. How often do you communicate with this co-worker? Categories: every day, several times a week, several times a month, or up to once a month.
3. What professional knowledge does this co-worker represent? No pre-specified categories.

Following pilot testing with employees external to the project, the project manager sent an email to all project participants asking them to respond to the questionnaire. With this managerial recognition of the questionnaire as an extra motivation to respond, 77% of the 22 project participants responded to the questionnaire.

After the questionnaire survey, two project participants were selected for *validation interviews*. The interviews followed a general recommendation in bibliometrics by validating the quality and practical potential of the personometric maps against the domain knowledge of selected project participants [19]. The selection of the two interviewees was based on three criteria: (a) position on the personometric maps, (b) frequency of communications with colleagues, and (c) experience with R&D projects. Thus, one interviewee had a central position on the maps, the other a peripheral position. Both interviews concerned the general information-seeking behaviour of the project participants and their perception of the accuracy and practical potential of the personometric maps, which were shown to and discussed with the interviewees during the interviews. The interviews, which lasted about an hour each, were audio recorded and subsequently transcribed.

4.2 Production of Personometric Maps

The questionnaire data, which form the basis for the personometric maps, are collected at one point in time, whereas data in conventional bibliometric analyses are accumulated over time. This means that we cannot count the frequency of communications in the same way as the frequency of citations is normally counted. As frequency provides a rough estimate of importance, we believe that assigning frequency weights to communications will substantially improve personometric maps by bringing out more differences and details. We used questions 1 and 2 from the questionnaire for this purpose:

1. Initiation of communications. We assigned double weight to self-initiated communications because people are likely to have a more valid memory of their own enquiries and to avoid that employees inflate their own position on the maps.
2. Frequency of communications. We assigned higher weights to more frequent communications, see Table 1. The weights convert the response categories into an approximate number of monthly communications.

Table 1. Weights assigned to communications

Question	Response category	Weight
1. Who typically initiates communications?	You	x2
	Her/him	x1
	Equally split	x1
2. How often do you communicate with this co-worker?	Every day	20
	Several times a week	8
	Several times a month	4
	Up to once a month	1

Inspired by White and McCain [24], the answers to question 3 (What professional knowledge does this co-worker represent?) were converted into slightly generalized competence descriptions and all persons on the personometric maps were labelled with the generalized competence most frequently ascribed to them.

The personometric maps were generated with *Bibexcel* (www.umu.se/inforsk/Bibexcel), which uses multidimensional scaling to determine the layout of the maps. Multidimensional scaling is restricted to data sets of limited size, so whereas multidimensional scaling can handle the number of members in most project groups it will typically not be possible to make maps of entire organizations. Computationally this limitation can be overcome by choosing other visualization techniques [see, e.g., 3] but as maps become large they also become increasingly difficult to make sense of. Thus, for large data sets there may be a need for alternatives to maps.

4.3 Within-Project Communication Patterns

Fig. 2 is a map of the communication structure *within* the project. Each circle represents a person and each line represents communications between persons. The size of a circle indicates the accumulated number of times the person has been mentioned in the questionnaires, while the thickness of a line indicates the frequency of communications between the two persons connected by the line. The thicker the line, the more they communicate. Further, circles clustered close to each other indicate that these persons have similar communication patterns in the sense that they tend to communicate with the same people and to about the same extent.

The map shows a strong central person, the project manager (no. 21). As indicated by the size of her circle, the project manager is the project participant involved in the largest number of within-project communications. Her position close to the centre of the map indicates that she communicates with most of the other project participants. The map suggests that the project manager along with an electro-acoustics engineer (no. 10) and a mechanical engineer (no. 4) form the centre of the project. They are all three involved in lots of communications, and there are strong similarities in their communication patterns. Continuing the exploration of the map, the project participants seem to form two rings around the centre. The inner ring (participants 1, 5, 8, 14, 16, 20, 22, and possibly 11 and 17) includes people from the more peripheral site as well as recently hired people. This sets the inner ring apart from the centre, which consists of three longstanding employees from the main site. The outer ring (participants 2, 3, 6, 7, 9, 12, 13, 15, 18, 19, and possibly 11 and 17) is, however, similar to the inner ring in its mix of people from the two sites and in its mix of recently hired and longstanding employees. To further explore differences between the inner and outer ring we will look at the competences represented by the project participants.

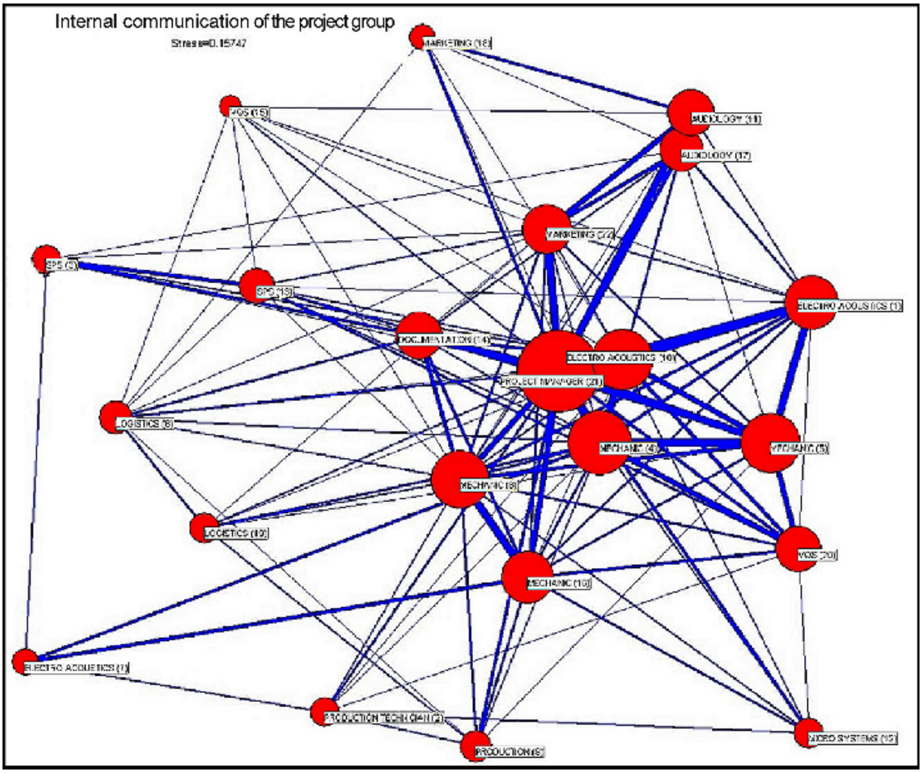

Fig. 2. Within-project personometric map. The fit between the data and the map is satisfactory, Kruskal's [15] stress measure gives a *badness of fit* of 0.16 (0 indicates a perfect fit)

Fig. 3 shows the project participants grouped by the competence most frequently ascribed to them. The project participants in most of the eleven competence groups are quite close together, indicating similar communication patterns. Group 8 on the map exemplifies that personometric analyses may reveal similarities between persons who are at different sites and in different organizational units (here, production and R&D). However, a few groups (4 and 6) contain project participants far apart on the personometric map. This reflects differences in the involved project participants' secondary competences and the separation between the two physical sites. As an example, the project participant in the lower left corner of group 4 is at the more peripheral site whereas the other participants in the group are at the main site. Several competence groups (2, 4, and 6) span both the inner ring and the outer ring. These groups could be seen as having a representative in the inner ring who acts as an intermediary between the group and the centre of the project. Finally, *Audiology* and

Marketing (groups 2 and 3) are somewhat removed from the centre of the map although the total weighted communications of the participants in these two groups are high. The synergy between these two groups as well as within the *Audiology* group results in *Audiology* and *Marketing* standing out as relatively autonomous and, consequently, as somewhat removed from the centre of the map.

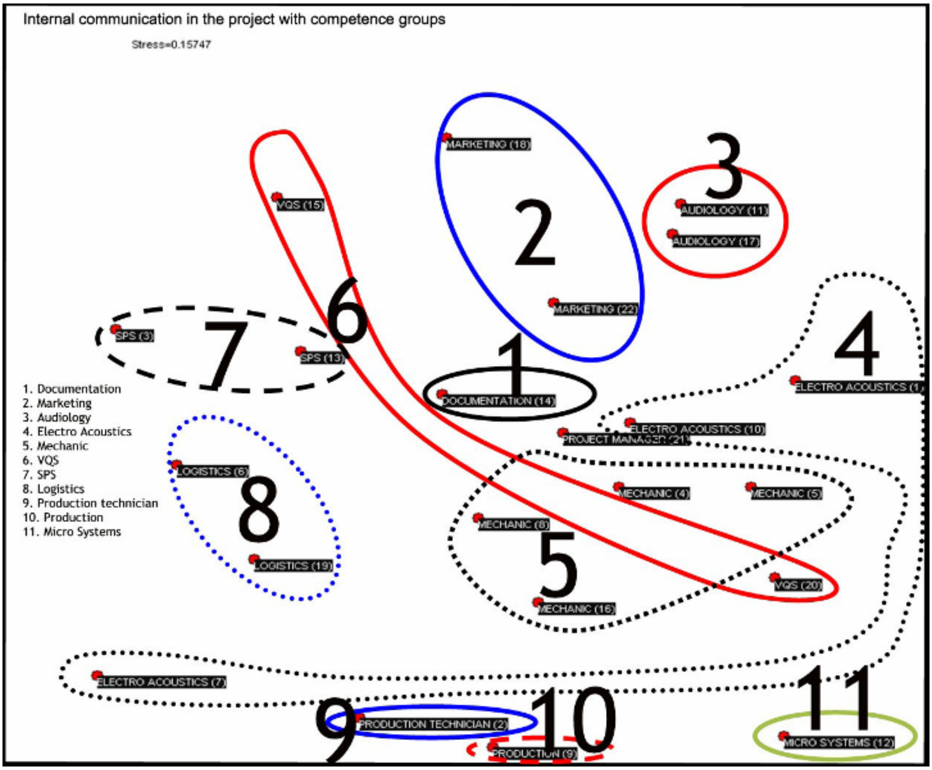

Fig. 3. Project participants divided into competence groups

4.4 Communications with People External to the Project

The project participants' total weighted communications are evenly split between within-project communications and communications with people external to the project. The vast majority of the communications with people external to the project are with other colleagues in the organization. Only 2% of the project participants' weighted communications are with people external to the organization. This suggests a competitive industrial setting in which small advancements in knowledge may have substantial commercial value [26]. In such settings project participants must carefully balance the capacity of their organization to exploit exclusive knowledge against the faster progress that may result from collaboration with outsiders.

Fig. 4 shows communications among all persons – both project participants and people external to the project – who were involved in ten or more communications. This personometric map provides strong evidence that the competences brought to bear on the project are not limited to those of the project participants. The map is characterized by a strong centralisation around what conceivably constitutes the core of the project with respect to persons as well as competence areas, but it extends into a complex network of interpersonal connections within the organization, and outside of it. This emphasizes the importance of having a well-developed personal network and, just as importantly, a good grasp of the network in general. There may be considerable strategic potential in using personometric maps to get an overview of where project participants turn for information as well as to identify important competences not sufficiently covered internal to the organization.

4.5 Validation

The objective of the validation interviews was to have project participants (a) assess the accuracy and understandability of the personometric maps and (b) discuss their practical potential as a means of supporting people finding.

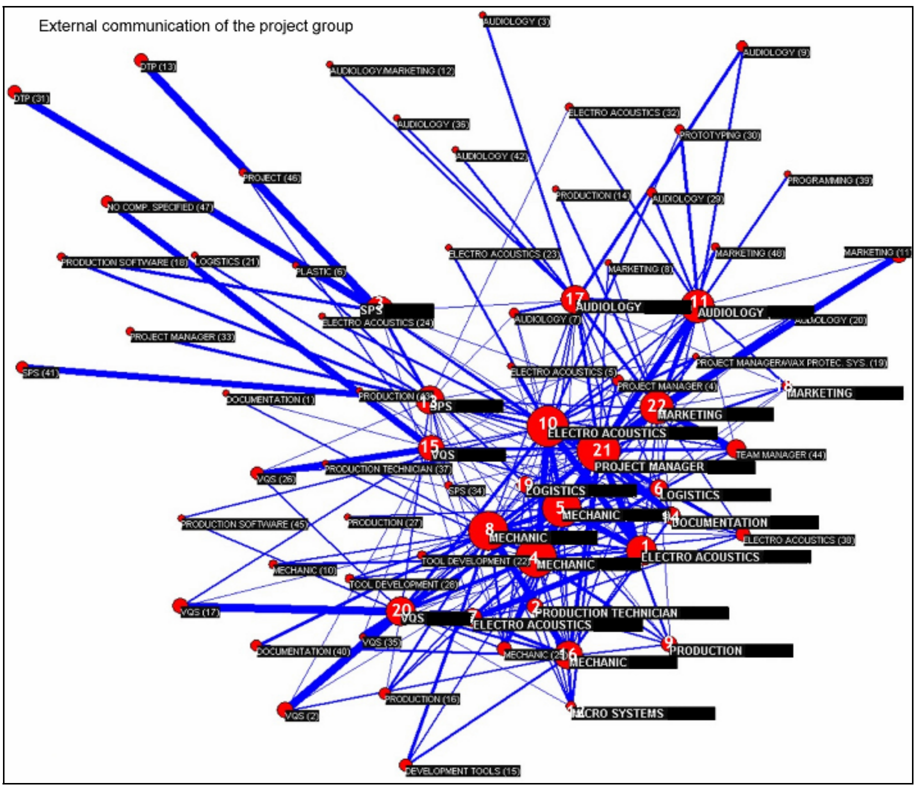

Fig. 4. Personometric map for both project-internal and project-external communications. The fit between the data and the map is good, Kruskal's [15] stress measure gives a *badness of fit* of 0.06

Prior to introducing the personometric maps, the interviewees were asked to name the project participants they considered most knowledgeable of who knows what. Both interviewees named project participants 4, 8, and 21. On the personometric maps participants 4 and 21 are two of the three persons in the centre of the project, and participant 8 is located in the inner ring. When shown the maps, both interviewees found them in accordance with their own image of the project, and they were readily able to interpret the general structure of the maps and provide explanations for various details. For example, the distance between some project participants on the maps was explained by their physical dissociation owing to the two separate sites, and a group of participants located close to each other on the maps was recognized as a subgroup responsible for the development of a new component. This suggests that the personometric maps were both sufficiently accurate and sufficiently easy to understand to provide the basis for a system supporting project participants in identifying colleagues to approach in different situations.

Interviewee A (R&D engineer, central position, two years in Oticon) found the maps very informative and was particularly positive toward using personometric maps as a way of visualizing the communication and competence patterns of old projects. Maps of old projects would retain information about project participants' communications and competences, and keep a record of important information sources external to the project group. Interviewee A emphasized that old projects are an important entry point in searches for information within the organization and that personometric maps appear to provide useful information that is otherwise not readily available. Further, interviewee A believed automated data collection was necessary for personometric maps to remain up to date, and he mentioned the privacy and status/power issues involved in making communication and competence patterns explicitly visible.

Interviewee B (production engineer, peripheral position, less than a year in Oticon) had more doubts about the potential of the maps. Due to her role in the project, interviewee B did not interact much with the other project participants and, consequently, she did not perceive that the personometric maps would ease her day-to-day work. She suggested that the maps would be more relevant for project participants who communicated more or were closer to R&D, and that they might relieve the project manager from many communications where she is merely asked for the name of the most appropriate project participant to contact. Nevertheless, the maps made interviewee B aware of project participants she had hitherto been unaware of, because "I'm not sitting down there, and I'm very bad at names."

4.6 Limitations

Our empirical study has several limitations, which should be remembered in interpreting our results. First, the study is based on data collected at one point in time. People's competences and their roles in projects are, however, not static but evolve over time. This suggests that data should be collected continuously or at regular intervals. Second, in this study data were collected by means of a questionnaire. In practical applications of personometric maps, (semi-)automated data collection appears necessary to keep the maps up to date over longer periods of time. Extracting data about communication patterns directly from, for example, logs of phone calls and emails will also provide data sufficiently fine-grained to count actual frequencies of communications, rather than have people estimate them, as in this study. Third, the project consisted of 22 participants. While very many projects are this size or smaller it remains unknown whether personometric maps scale to considerably larger projects. For larger projects interactive maps may be superior to the static maps studied in this paper. Fourth, the personometric maps have only been validated by people internal to the project. People external to the project will lack project participants' contextual knowledge and it is unknown to what extent this makes the maps less useful to them. These limitations suggest important areas of future work on personometric mapping.

5 Conclusion

Multi-site projects are prevalent in R&D, and engineers increasingly experience that information pertinent to their work is held by remote co-workers external to the group of colleagues with whom they regularly meet face to face. Personometrics, as put forward in this study, intends to advance our understanding of people as information objects by mapping and visualizing the intellectual structures embedded in interpersonal communication patterns. An important practical application of personometrics is to provide a conceptual basis and feasible techniques for the design of systems that support engineers in ad hoc identification of distributed colleagues with specified competences.

By equating the co-occurrence of interpersonal communications with co-citations in scholarly writings, personometrics extends the scope of bibliometric citation techniques to the investigation, mapping, and visualization of project participants' communication and competence patterns. In this study we have demonstrated how personometric maps can be constructed from empirical data about the interpersonal communications made by a group of R&D engineers. These personometric maps, which project participants find accurate and easy to understand, show that communications in the project centre around the project manager and two other longstanding employees, all at the main site. The other project participants form two rings around the centre. Participants with identical primary competences are frequently distributed across sites but mostly appear close to each other on the maps, indicating similar communication patterns. However, three competence groups span both the outer and inner ring, suggesting that these groups have a representative who mediates between the group and the centre of the project.

Half of the project participants' communications are with colleagues external to the project and intended to complement the expertise available in the project and avoid rework. Project participants see personometric maps of old projects as particularly useful because old projects are important entry points in searches for information and the maps retain information that is indicative of people's competences and otherwise not readily available. By also including communications with people external to the organization, in this project only 2% of the communications, personometric maps may identify strategically important competences not sufficiently covered within an organization.

In relation to practical application of personometric maps, (semi-)automated data collection appears necessary but an occasional, supplementary questionnaire may provide additional data about face-to-face communications and improve the possibilities of removing noise in the data by triangulation. The use practices that emerge when personometric maps become an established means of people finding in an organization should be examined to assess and refine this type of analysis. While exploratory, this study suggests that personometric analysis holds promise.

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