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Voor Susanne, Guus en Joep

In herinnering aan Betty Noyons-Luszczek

Preface

Bibliometric maps of science are landscapes of scientific research fields created by quantitative analysis of bibliographic data. In such maps the 'cities' are, for instance, research topics. Topics with a strong cognitive relation are in each other's vicinity and topics with a weak relation are distant from each other. These maps have several domains of application. As a policy supportive tool they can be applied to overview the structure of a research field and to monitor its evolution. This book contributes to the development of this application of bibliometric maps.

There has been much discussion about the trustworthiness and utility of these landscapes ("What does the map show?") since their birth in the 1960s. In this book, a methodology and procedure is proposed to allow both expert (trustworthiness) and user (utility) to evaluate and validate the maps. Furthermore, a procedure is designed to extract field-specific keywords from publication data,used to create the maps. Thus, the method becomes independent from database-specific classification schemes and thesauri. As a result, a research field may be delineated and mapped on the basis of more than one publication database.

The proposed method opens new doors for 'evaluative bibliometrics' and is prepared for the advent of electronic publishing in science.

Most of the case studies presented in this book were performed in the framework of contract research and of other externally financed research programs. The 'umbrella' of our work was mainly funded by the Netherlands Organization for Scientific Research (NWO) and by Elsevier Science.

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Part I Evolution of Science Maps

1 Introduction

When apples are ripe, they fall readily

(Sir Francis Galton 1822-1911)

The above quotation was used by Price (1963) to illustrate the fact that scientific innovations or discoveries mostly arise from ongoing developments, rather than pop up by surprise. In the same way, the developments presented in this book spring from several developments in the recent past. These developments concern cultural changes and technological opportunities.

Ziman (1994) argues that science has reached a steady state. By this he means that the proportional investment in scientific research has remained for a longer period of time at a similar level (average percentage of the gross national product). At the same time a tendency towards improving the quality (in all its aspects) of scientific research is being pursued. The societal relevance has become an important issue for funding scientific research since the seventies. Furthermore, evaluation of scientific research has become a major issue for science policy. Scientific groups are being evaluated by peers (visitations) in order to assess the emphasis and impact of their activities. More and more these judgements by peers get accompanied by bibliometric evaluation: *what do scientists publish and to what extent is this appreciated by the scientific community?*

As a result of this intended efficiency of scientific research, the exponential growth of science is still going on, in spite of the steady state of science investments. There are indications (Van Raan, 2000) that the growth factor with a doubling time of 15 years (c.f., Price, 1963 and Ziman, 1984) still applies. In order to scrutinize developments in science and in research fields, a tool providing an overview is essential. Price already noted the impossibility of one person to keep up with all developments in a field (Price, 1963).

It could be discussed which form such a tool should have. Following the argument provided by Ziman (1978) to visualize theories, this may best be a map. The knowledge output of a field may well be seen as a current theory (or set of theories).

> It is natural to refer to such a representation as a map. It is important to emphasize that this reference is itself metaphorical. Scientific knowledge is a peculiar epi-phenomenon of human existence, and can only be uniquely itself. There seems no absolute necessity that it should be structurally isomorphous with anything so topically specialized as, say, a graph of vertices (in map language, 'places') connected by edges (e.g., 'roads') on a manifold ('sheet of paper') of a few (two, or perhaps three)

> dimensions. It could conceivably – and perhaps at times ought – to take wilder, more diffuse forms.
>
> But the metaphor is extraordinarily powerful and suggestive. There are good reasons to believe that human beings are adapted neurologically and psychologically to comprehend information presented in map form.
>
> (Ziman 1978, p. 78)

And to explain this metaphor some more:

> (…) What we also recognize is that a sketch map can convey significant and reliable information, without being metrically accurate. What such a map represents of course is the topology of the relationships between recognizable geographical features – for example, the sequence of stations and their interconnections on the London Underground. In many fields of science, what we call qualitative knowledge has these characteristics – for example, the ethologist's account of the courtship behaviour of birds or baboons. Is such knowledge 'unscientifical' because it is not quantitative – because the subway map does not, so to speak, show the actual positions of the stations by latitude and longitude. The question is, rather, whether the sketch or diagram correctly represents the significant relationship between identifiable entities within that field of knowledge – often a ver moot point that cannot be resolved by mechanical counting or 'measuring'.
>
> (Ziman, 1978. p. 84)

During the past three decennia science maps have been created to monitor research field structures. However, the utility has been questioned at the same time. An often heard comment to science maps is: 'interesting, but what can we do with it?' Moreover, the validity of the generated structure was often doubted: 'does this map really represent the structure of the field?'

Although the scepsis towards maps of science will probably always exist, we have made an attempt to improve the utility by making the maps interactive. The technological developments to access the Internet, provide an excellent platform to accomplish that. The graphical interfaces developed to browse through the worldwide web enable us to create clickable maps. Through this interactivity, the validation of the generated structure (the map) becomes much better and easier. Moreover, the interactivity improves the utility of the map as users have more choice to extract information from the maps.

In view of this utility, we focus in this book on the applicability of science maps as a science policy and research management support tool. It concerns the procedure to construct the field structure (the map) as well as the information 'product'. Regarding the procedure, we propose an interface to enable the field expert to provide goal-directed input to the preliminary results of the analyses. With respect to the information product (the map and additives), we provide the user with an interface both to extract information in view of the raised issue, and to evaluate the validity of the generated structure (2D map). As mentioned before, this interface does not primarily improve the methodology to construct a map, but rather improves its utility. To illustrate the utility, the interface can be compared to the computerized route planner for travelers. Ten years ago, a traveler needed a certain amount of geographical maps in order to find his way in a country. A traveler by car needed less detailed and therefore fewer maps than a traveler by foot. Still, each time he took a look at the map, he had to list new instructions to plan the route to his goal. All the information he needed would already be on the maps, but each time he would have to determine his present location and to adjust his perspective in order to be able to extract the relevant information. Nowadays, a computerized route planner enables a traveler to extract the same information each time he is consulted. However, in this case the relevant information can be provided instantly without all the 'surrounding' information. Like the paper maps, the route planner incorporates all the information but focuses on the relevant instructions, at any chosen level of detail.

In the case of science maps, the available information could be printed on paper and through a clever reference system all the information could be disclosed. However, the user would easily become overwhelmed by the amount of 'potential' information. By presenting the map of a science field, and allowing the user to extract only the information he is interested in, he is less likely to become overwhelmed. Thus, he will be able to determine easily the proper perspective and to disclose relevant information at any level of detail.

In a more methodological sense, we have explored in great detail the possibilities of using titles and abstracts to extract keywords to create the maps. The application of a linguistic analysis appeared to add an essential component to the co-word analysis. Hence, the selection of relevant keywords to structure a research field became possible without the input of (often absent in bibliographic databases) indexed terms.

1.1 Introduction to bibliometrics

Bibliometrics is another word for quantitative analysis of bibliographic data. Bibliographic data discloses the main elements of a publication. For information retrieval in libraries, it is a most important data source. The elements are used to retrieve information about publication data from large bibliographic databases. Nowadays, bibliometrics has at least four areas of application.

Performance analysis

In this area, scientific research units are evaluated on the basis of performance within a particular science field. These units can be on all levels of aggregation: continents, countries, regions, universities, faculties, departments or even individuals. In most cases performance is measured and compared to other units. Performance has three main aspects: activity, productivity and impact. Generally, activity is measured by the number of publications within a certain time span, but some studies measure activity by the number of published pages. By linking the activity of a research unit (for instance, a country) to the number of inhabitants (or active scientists), or the Gross National Product, an indication of productivity is obtained. By linking the scientific output of a research unit to the number of citations received, an indication of impact, influence, or at least of visibility is obtained.

Mapping science

A second application area of bibliometrics, concerns the monitoring of scientific activity and science evolution. This area of bibliometrics unravels a structure of science and investigates its development. The research output (in this case, publications) is subject to clustering and scaling analyses in order to determine the structure and to monitor its changes. Regarding the policy relevance of this particular area, it is assumed that this approach indicates what the important areas in a science field are, how they develop(ed) and what we may expect in the future. This area is known as 'mapping of science' or 'cartography of science'.

This application is particularly important for science policy in view of the ever blurring of disciplinary boundaries of science, and growth of scientific output (Braam, Moed and Van Raan, 1989).

Information retrieval

A third area in which quantitative studies of bibliographic data are applied, is the field of Information Retrieval. Searching for publications about a topic *A*, someone may be interested in publications about a related topic *B*. The relatedness of topic *A* and *B* can be determined by bibliometrics (e. g., word co-occurrences). The idea is that patterns in frequency distributions in bibliographic databases can be used to detect important characteristics, which can be useful to retrieve the proper information from these databases (Egghe and Rousseau, 1990). Recently, the application of, in particular, citation data, has become less popular. In Ingwersen (1996) a plea for reinforcement has been published. Furthermore, Garfield (1998) supports this application.

Library management

Finally, in libraries bibliometric data is used to manage the (journal) collection. This part of library operations research may use, for instance, the impact of a journal (a measure based on the number of citations received per article) to maintain and update a library collection (e.g., Van Hooydonk et al., 1994). An extensive overview of the techniques and applications is presented in Egghe and Rousseau (1990).

Although bibliometrics has a long history, the most frequently used application is rather young. It concerns the use of bibliometric data to evaluate the scientific performance in terms of published papers and their impact. A scientific publication discloses the methods, results, and perspectives of research. A database containing all scientific publications is therefore virtually a source of all scientific knowledge. Evaluative bibliometricians base their research on these assumptions. 'Evaluative bibliometrics', a term coined by Narin (1976), concerns the quantitative analysis of bibliographic data of scientific publications with the objective to find characteristics of research performance. There are, of course, some important issues to be taken into consideration in order to operationalize bibliographic data to evaluative bibliometric studies.

The achievements of science are reported in scientific publications. It is a basic principle of science that research results are made public (Ziman, 1984). Scientific discourse is vital for progress (among other functions, c.f. Roosendaal and Geurts, 1999). Most of it is published in discussions in journals (Moed, 1989).

> Although a large part of the communication does not take place in the form of scientific journals, (…) it is assumed that eventually, all important research findings are reported in the serial literature. (Moed 1989, p. 4)

This observation is of great importance. An evaluation based on bibliographic data over a 'longer' period of time, requires a certain stability. That is, a comparison of output indicators from year to year, requires a certain consistency of sources. The use of serials 'guarantees' such a consistency. The use of books (as unique publications) does not. Furthermore, the availability of electronic data is of vital importance in view of the reliability and utility of the study. Evaluation of the activity of a research entity (person, institute, university, country, etc.), demands a publication database of that particular entity, and of at least one comparable entity. The collection of objective data requires a database that is objectively composed and 'publicly' available to guarantee the reproducibility of the results. The number of 'reference points' (i.e., to which a research entity's performance is compared) correlates with the reliability of the results. In other words, the more entities included in a study, the more reliable a study becomes. Ideally, a research performance study makes use of the worldwide publication collection in a certain field in order to assess the performance of a particular research unit. Moreover, evaluative bibliometric studies often aim at presenting the worldwide characteristics of a certain field in terms of scientific activity. For these reasons, we cannot do without huge worldwide bibliographic databases of scientific publications. In most cases such databases disclose data from publications in serials. Some examples of important ones are:

- The ISI Citation Indexes (SCI, SSCI, A&HCI, etc.): a worldwide, though somewhat Anglo-Saxon biased multidisciplinary database containing standard bibliographic data including all addresses of authors mentioned in the publication, abstracts, and all the cited references. These properties make the ISI databases unique. Wouters (1999) provides an extensive overview of the history of this famous database. The Science Citation Index, the Social Science Citation Index, and the Arts & Humanities Citation Index cover journal articles only. The ISI specialty Indexes (Biotechnology, Neuroscience, Materials Science, Biochemistry & Biophysics, Chemistry and Computer Science & Mathematics) contain other serials material as well (conference proceedings etc.);
- MEDLINE: a standard worldwide biomedical bibliographic database (including abstracts) produced by the National Library of Medicine (NLM) with added keywords and classification. It contains only the first author's address and no references;
- INSPEC (including Physics Briefs): a worldwide database in the fields of Physics, Electrical & Electronic Engineering, Computer Engineering, and Information Technology. It contains standard bibliographic data as well as the authors' abstracts, an added classification, and keywords. Since 1995 the Physics Briefs database is included as well. It contains only the first author's address and no references;
- COMPENDEX: an INSPEC-like database in the field of Engineering. It contains only the first author's address and no references;
- Chemical Abstracts: an extensive worldwide abstracts database in chemistry, biochemistry and chemical engineering, including all relevant bibliographic data. Unique is its coverage of both scientific and patent publication data.
- PASCAL: a multidisciplinary database covering publications in several languages. More than 90% of the documents are journal articles, The rest are conference proceedings, theses and monographs. Provided references, all relevant bibliographic fields are disclosed.

1.2 Introduction to science maps

A science map is two or three dimensional representation of a science field, a 'landscape of science', where the items in the map refer to themes and topics in the mapped field, like cities on a geographical map. In these maps the items are positioned in relation to each other, in such a way that those topics that are cognitively related to each other, are positioned in each other's vicinity, and those not or hardly related, are distant from each other.

The most well-known maps of science are those based on bibliographical data, the bibliometric maps of science. As scientific literature is assumed to represent scientific activity (Ziman, 1984; Merton, 1942), or at least in the form of scientific 'production', a map based on scientific publication data within a science field *A* can be considered to represent the structure of *A*. It will depend on the information used to construct the map, what kind of structure is generated, and how 'good', i.e., to what extent the structure is recognized by the field expert.

The maps are constructed by the co-occurrence information principle, i.e., the more two elements occur together in one and the same document, the more they will be identified as being closely related. The science mapping principle dictates that the more related two elements are, the closer to each other they will be positioned in a map.

Many different bibliographic elements (fields) from a scientific publications database may be used to generate a structure. Each element reveals a specific structure, unique in a sense, but always related to the structures based on other elements. Generally bibliographic databases disclose per document a range of bibliographic fields (elements). The important ones are:

- authors of the publication;
- title of the publication;
- source in which the document is published, e.g., the journal, proceedings or book;
- year of publication;
- address(es) of the (first) author(s);
- abstract of the publication.

In specialized bibliographic databases, other information may be included as well:

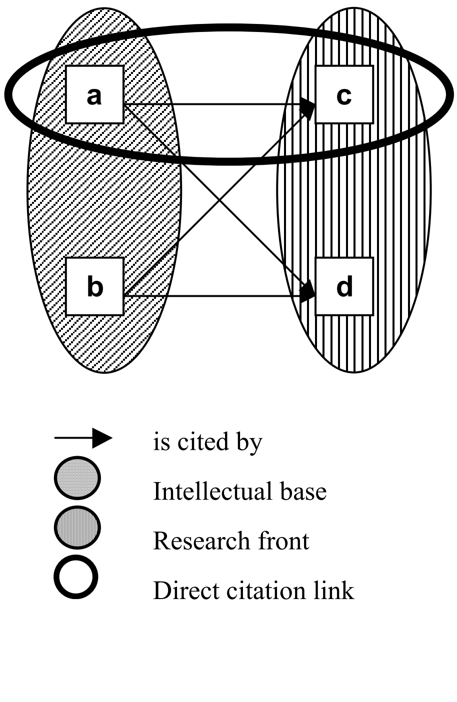
- cited references;
- publisher information of the source;
- keywords (provided by the author or journal editor);
- classification codes (added by the database producer);
- indexed terms (added by the database producer).

As discussed above, it depends on the data elements used to construct the map, what kind of structure is generated. A map based on co-occurrence of authors is more likely to unravel the 'social structure' of a science field, than a map based on co-occurrence of classification codes.

One of the most frequently used information elements in science mapping, in particular in the seventies and eighties, is the cited reference. A most intriguing aspect of the 'publication to publication relation' by citation, is its variety. Apart from the *reason* why a particular publication is cited by the other, the formal relation has at least six different ways of linking publications. First, there are three elements in the formal citation of a specific journal article to another that may be used to define a relation.

- the cited publication as such;
- the cited journal;
- the cited author.

Furthermore, a relation between publications may be defined either by their direct citation relation (*c* cites *a*), or by the fact that *a* and *b* are both 'co-cited' *by* other publications (*c* as well as *d* cite both *a* and *b*). In view of the latter relation they are considered to belong to the same part of a field's intellectual *base* (Persson, 1994). The relation between *c* and *d* may also be determined by the fact that they *cite to* the same publication(s). In that case they are 'bibliographically coupled' and these publications are considered to belong to the same part of a field's research *front*. In such terms, the *base* relates to the past and the *front* relates to the present.



1.3 Introduction to science maps as policy-supportive tool

Since the seventies, science maps have been developed to be used as policy supportive tool. They have been based mostly on co-citation and co-word data. The co-citation techniques were developed in the seventies (Small, 1973; Small and Griffith, 1974; Griffith et al., 1974; Garfield, Malin and Small, 1978). In the eighties, a series of projects were set up to explore the possibilities and limitations of co-citation analysis as policy supportive tool (Mombers et al, 1985; Franklin & Johnston, 1988). In the same period, co-word techniques were developed for policy purposes. Particularly, at the École National Supérieure des Mines, together with other French researchers and researchers from the Netherlands and England, Michel Callon made an important effort to establish this tool, called *Leximappe* (Callon et al., 1983; Callon, Law and Rip, 1986; and Law et al., 1988). Callon and his colleagues mistrust the citing behavior of scientific authors. They argued that a scientist may have many reasons to cite an other publication. Apart from 'non-scientific' reasons to cite (see Van Raan, 1998), scientists may cite, on the one hand, earlier work for different reasons within the argumentation of the *citing* publication. On the other hand, different parts of the argumentation in the *cited* publication may be the reason to be cited.

At the end of the eighties, co-citation and co-word mapping of science suffered a great deal of criticism. Data and method of co-citation analysis were criticized (Edge, 1979; Hicks, 1987; Oberski, 1988). Moreover, the results (the generated maps) were rejected and the utility was heavily questioned (Healey, Rothman and Hoch, 1986). It must have been this debate that has blocked the development of at least co-citation modeling during the nineties. It seems that studies at the Leiden Centre for Science and Technology Studies (CWTS) of Braam (1991), Tijssen (1992), and Peters & Van Raan (1993) have been the last serious attempts in methodological development for a long period of time. Case studies (with no methodological developments) have still been published after this period of time. At CWTS, the emphasis shifted to co-word analysis. One of the reasons was the possibility to create maps based on other databases than ISI's. For instance to map an 'applied' field in which most research is published in proceedings, co-citation analysis is not appropriate, as proceedings papers contain very few references. A more fundamental, 'scientific' reason for the shift is the fact that co-citation analysis precludes a combined study of field dynamics and actors' activity (see Chapter 6). The idea is that a trend analysis of actors' activities can only be combined with a study of the field dynamics, if a certain rigidity is applied to the identified structure (delineation of subdomains by words or citations). For instance, if we are analyzing field dynamics from period t to $t+1$, the subdomain delineation may be determined by the $t+1$ data and this delineation is to be applied to t. In this example, we would be able to compare the evolution of and interaction between during t and $t+1$, as well as to investigate the activity trends of actors in a meaningful way. By using citations, we may encounter severe problems as the citations used to structure *t+1*, may not have been published yet in *t*. The citations are 'replaced' by others per se, because scientific progress is reported by publication. A word (being a building block of any publication) does not have to be replaced per se. In view of the scientific communication, the 'invention' of new words is not preferable. As a result, an average publication is likely to have a 'shorter life' than an average word or phrase.

Since the mid nineties, science mapping experiences some sort of revival. Most likely, this revival is due to the increasing interest in information technology. The applicability of new analytical software (e.g., neural networks, Grivel, Mutschke and Polanco, 1995) and the availability of hypertext software (Lin, 1997; Chen et al., 1998), provided new impulses for science mapping, in particular based on co-word data.

Roughly, two types of science maps can be distinguished. One represents the network of items on which the map is based. The other type represents the structure of the field on a higher level of aggregation (a thematic map, cf. Law et al., 1988). Technically, in the latter type a clustering analysis is performed on the data, which is directly input for the map of the former type. The identified clusters[1] are mapped in relation to each other, thus providing a thematic or general overview map. The distinction between the two types is by no means trivial. If we consider science maps as a tool for research policy, each type can have its own function in the communication process from scientometrician to (policy-related) user. Maps of science can be considered a tool to translate scientific activities to science/research policy. In order to assure the validity and utility of this tool, the (mapped) scientific researchers should validate the derived structure. As mentioned before, science maps can be located somewhere in-between the communication line from science to policy and management. Consequently, the network map is closer to the science end, and the thematic map closer to the policy end (see Figure 1-1).

[1] Callon refers to them as themes. We refer to them as subdomains.

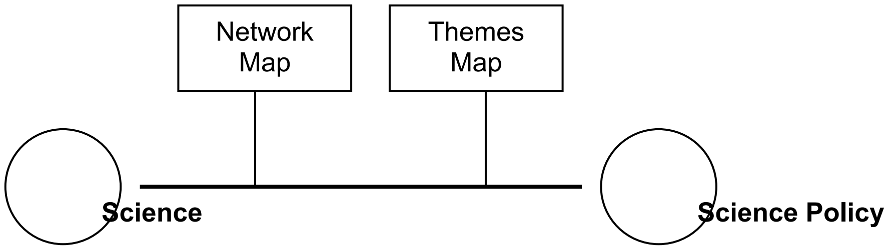


Figure 1-1 Schematic location of network maps and thematic maps

If we take the example of co-word maps, scientists recognize topics (terms, words) in the network map mainly in terms of specific research themes and their relations. Policy makers, however, prefer to see more 'utility' in the map, mainly in terms of 'overview', i.e., clusters of topics (subdomains). Analysis of these subdomains allow users to filter out general actor and field characteristics.

The digitalization of maps – i.e., clickable maps on a computer screen, rather than on paper –provides opportunities to merge both kinds into one 'product'. The interactivity of such maps allows the user in a broad sense (i.e., 'from politician to scientist') to retrieve his/her information of interest without being 'annoyed' with other information.

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2 Principles of Science Maps

In this chapter the principles of a science map are discussed. These principles account for a trustworthy and useful process and procedure to build a science map which can be used as a policy supportive tool in terms of evaluative bibliometrics.

2.1 What do maps show?

The central question of this section is an important issue in science (and technology) mapping: *what do the maps show*? By discussing the most important principles underlying maps of science (listed below), this question will be addressed.

1. Maps of science as a tool for science policy should represent the scientific knowledge. Scientific knowledge is represented per se by *research output*;
2. Bibliometric science maps are constructed on the basis of *publication data*;
3. Provided that the research output of a field is well covered in a *bibliographic database*, this field can be represented by (a selection of data from) this database;
4. By using *content describing elements* (CDE, the building blocks of a publication description), each publication can be characterized;
5. With help of co-occurrence data of the most frequently used CDEs within a bibliographic database, the *structure of the database* can be unraveled;
6. Under the assumption of principle 3 and 5, a structured bibliographic database of publications in field A represents the *structure of field* A;
7. The *dynamics of the structure* based on the changing co-occurrences, represent the dynamics of the field, as related to the structure of the field.

Each principle will be discussed from the perspective of the matter addressed in this book. We do not claim that this list is exhaustive. Other applications of science maps (e.g., information retrieval) may have other principles.

Research output

Maps to be used as policy-supportive tools should represent scientific knowledge. Policy-related users want to know the structure of this knowledge *and* its evolution in order to validate their activities or explore future developments.

> Whatever scientists think or say individually, their discoveries cannot be regarded as belonging to scientific knowledge until they have been reported to the world and put on permanent record.
>
> (Ziman 1984, p. 58)

Following the argumentation of Ziman (1984), we should conclude that the map particularly is a suitable representation of scientific knowledge. He states that:

> A mature body of scientific knowledge is like a map. The structure of some region is represented by the relative positions of various conventional symbols, each standing for some selected category or aspect of the real world. (…) The map metaphor also suggests that scientific knowledge is a multiply connected network of concepts, where the validity of any particular proposition does not depend solely on one or two other theoretical propositions or empirical observations.
>
> (Ziman 1984, p. 49)

However nice this metaphor looks, a *map* is 'just' a virtual representation, possibly with no reference to the 'real, physical world'. From the objectivity viewpoint, the data itself should create a structure: the self-organizing maps (Kohonen, 1990) of science. This may cause the map to become incomprehensible and unpredictable if it does not refer to the perception of the field structure by an expert. For this particular reason, the interpretation and validation by experts is of vital importance for the *utility*. If a map is not interpretable for a field expert, it means that the map is not useful for policy supportive means. The map has no reference to the world according to the policy-related user and thus the map cannot contribute to a policy or management discussion.

Publication data

A map presents the structure of a field in a particular period of time (T). The selected publications were published during that period of time. The map based on these publications therefore represent the structure of the field in period T. The *publications* in T, however, represent the *research* performed in a preceding period. It is very difficult to determine the time lag between (completion of) *research* and *publication*. For instance, if we look at publications in journals, in each stage from *research* to *publication*, several factors can be identified that affect the time-lag. At the stage from completion of the research to the first version of a publication, the available time of the researcher to write the article is involved, an sometimes in applied research, an embargo on the results set by the body that commissioned the study are just a few of them. In the process from *first submitted* to *final accepted* of a publication, factors like available time of the author to correct earlier versions, and time and availability of the referees, are at stake. In the process form the *acceptance* to *actual publication*, the backlog of a journal is not to be neglected. Unfortunately, not every journal has the same backlog. There are journals with a publication section for highly significant recent developments (in scientific or social sense) which have a small backlog, in most journals, however, it takes between six and eighteen months before the accepted version of an article is published. This may, but not necessarily, be field dependent.

Therefore, a map based on journal publications in *T* may represent the research performed in year *T-i,* where *i* is for instance 2 years. As presentations at conferences seem to be better updated with the present work of researchers, a map based on proceeding papers in *T*, may represent the research performed in *T-i*, whit *i* is between 1 and 'zero' (publication in the year of research). Again, it will depend on the objective of a study whether this is a problem. A mapping project aimed at unraveling the main structure of a field in a period of time longer than one or two years, will probably not be affected by a relatively short time lag. Moreover, clever selections (based on sources, document types, journal sets, or even on the output of excellent performing research groups) assure consistency of data, and thus reliability of results. Finally, science maps show the structure of the scientific output of researchers, not the research itself. Maps give an indication of how the knowledge is structured, under the assumption that knowledge is represented by the scientific output (Ziman, 1984).

An exploration of the publication delay as defined by the period of time between the date of submission and publication of an article has been reported by Luwel and Moed (1998). They are concerned with this phenomenon in view of the impact of publications (citations received).

Bibliographic database

The availability of reliable data is, beyond doubt, the most important condition for a valid bibliometric study. The choice for a particular database for a particular study does not solely depend on the consensus of bibliometricians. For an important part it depends a on the objective of the study. If the required indicators can be extracted from database *X* and both the users of the indicators and field experts approve of the database X to be used, there is no reason to use database *Y*, which may be a standard in bibliometrics. For instance, during the evaluation of the project presented in Chapter 9, experts in the evaluated field microelectronics stated that, as far as the most important developments were concerned, the field might as well have been represented by the bibliographic data of just a series of international conferences. On the other hand, a bibliometric study including impact data, 'must' use the ISI citation databases. Not (only) because they form a bibliometric standard thanks to its unique coverage (namely multidisciplinary), but (also) because they are the only databases containing cited references[2].

Another important consideration is that the scope of the database determines to a large extend the results of the mapping exercise. In Chapter 6 and 7, we report of a study of neural network research, based on data extracted from the INSPEC database. The scope of this database appeared to be relevant for the study, and the funding body (the German Ministry for Science and Technology, BMBF) agreed on that. Nevertheless,

[2] There is a specific field, high energy physics, which has its own database (SLAC-SPIRES) including cited references

experts in the field concluded afterwards that a considerable part of the field was not represented, being the research conducted within the behavioral sciences (cognitive psychology). As a result, we should refer to the monitored field as being mainly neural network physics and engineering.

Finally, Chapter 5 is referred to as another illustrative example. In this study, we mapped the field of 'optomechatronics' on the science side (publications) and on the technology side (patents). An important subfield observed in the science map appeared to be missing in map on the technology side. It concerned an area of software engineering. The most plausible reason for this is that software as such is difficult to be patented. As a result, the area mainly covered by software developments is hardly covered by a patent database, and thus hardly present in the technology map. It shows up, however, very well in the science map.

In order to answer the question '*what do the maps show*?' one should first answer the question '*what does the database cover*?' The map never shows more than the data discloses. nevertheless, a map is able to reveal hidden structures (within the data); structures which may not be obvious to field experts.

Content Describing Elements

The concept 'Content Describing Element' (CDE) is flexible. Some items in a bibliographic database are beyond doubt CDEs: title, abstract, classification codes, thesaurus terms. They are all able to describe the contents of an article in such a way that it is not easily mixed up with another. In other words, they are completely or to a large extent document-specific. Others, however, may be CDEs as well but are not or less specific for a particular document: author, journal, cited reference. In a search for interesting publications, a researcher often makes a first selection by choosing a particular journal, or a set of journals. Then, he scans titles and authors of the listed articles. In an alternative procedure, he may look up which (new) articles cite a particular publication or author. Thus, the contents are determined by journal, author, title and/or cited reference, or at the least by a combination of these elements.

By nature, CDEs seem to be appropriate elements to build a science field map. In that case the CDEs of publications must become CDEs of a bibliographic database and thus of a science field. For example, publication-specific keywords describe the publication (its main issues) to which they belong, and the field-specific keywords describe the contents (the main issues) of a field. As a result, the keywords of publication X (belonging to field A) are *candidate field keywords* for A, but they belong not necessarily to the most typical keywords for A.

In principle, to build a map we may use any CDE. Ziman (1978) states:

> Since science is more than personal knowledge, it can consist only of what can be communicated from person to person. The available media of human communication determine the forms,

> and to some extent the contents, of messages that make up scientific knowledge. To start with, as a crude 'zeroth-order approximation', we treat this as a strict limitation; to achieve the ultimate goal of consensuality, science must be capable of expression in an unambiguous public *language*.
>
> (Ziman 1978, p. 11)

This means that in every aspect of a publication a potential communication issue is captured. It will depend on the purpose of the map, which one to use. This dependency is caused both by the data, and by the user involved. For example, a map based on author co-occurrence data, primarily shows the 'social' structure of the field. Researchers working in one and the same institute, and having a good (professional) relationship, are more *likely* to co-author a publication than those who do not. So, from the data 'point of view' - that is, for which purpose should the data best be used - the aim of the map is of great importance. Therefore, should the map be aiming at unraveling the *social* structure, the author co-occurrence data seems most appropriate. On the other hand, if the map should be aiming at unraveling the *cognitive* structure, the author co-occurrence data may appear to be appropriate as well. However, in that case it is likely that the user would object. For an average user, a map based on author co-occurrence data does not *primarily* refer to the *cognitive*, but rather to the *social* representation. He would get confused because the map does not show a representation that refers to his perception of the field concerned. This observation seems trivial as it is illustrated by such opposite examples. If the CDEs are more similar, the discussion of this user dependency becomes more relevant. A cognitive map based on keywords retrieved from *titles* may, for instance, be rejected by an expert who primarily gives 'popularizing' titles to his publications, and may prefer controlled terms. An expert, however, who is most of the time working on new developments (including new topics) may prefer the titles (and abstracts) rather than controlled terms, because they may not cover new topics.

In most cases, the structuring of a field for science policy support is established by *co-word* analysis. The words or terms refer directly to topics and methods, and thus to the field cognition of experts and (other) users. In such analyses, the CDE discussion mainly focuses on the usage of a controlled vocabulary as opposed to free text. A controlled vocabulary relates to keywords taken from an existing list (i.e., thesaurus). This list is maintained and updated by experts in the field to which this list refers. In most specialized bibliographic databases, such keywords are added to publication documents. The usage of the controlled vocabulary has two main disadvantages. The first is best known as the 'indexer effect' (c.f., Healey, Rothman and Hoch, 1986). The indexed terms are added to publication by field experts. It will depend on the expertise (in all its facets) how trustworthy and appropriate this is done. The second disadvantage concerns the rigidity of indexed lists of terms. It will take some time before a new term (topic, theme, subject, method) is introduced into an index. In information retrieval this is an important point of discussion. The controlled vocabulary (indexed terms, descriptors, et cetera) is more precise (sometimes even more adequate) to be used in bibliographic searches, but lacks the, often important, feature of topicality. A 'free text' search in a bibliographic database returns documents containing up-to-date vocabulary but often omits documents with titles and abstracts in a slightly different jargon.

In policy-supportive studies, it will depend upon the aim of the project, what CDE is to be used. Bibliometric co-word mapping studies aiming at generating an exhaustive historical overview of a science field, will benefit from the usage of controlled terms, whereas studies aiming at exploring recent developments, will benefit from the usage of free text CDEs.

Therefore, in order to answer the question '*what do the maps show?*' first the question '*what do we want the maps to show?*' has to be answered. And in view of that question, it should be determined what kind of data is going to be used to build a map. Furthermore, it should be investigated whether the data and the resulting maps generate a picture of the field that reflects the 'representation' of the user, and is appropriate to answer the raised issue (the aim of a project). To deal with these questions, one should not only be flexible with respect to the information presented in a map, but also with respect to the process of building the maps. The user-bibliometrician interaction is vital for the results, and therefore for the success of bibliometric mapping.

Structure of the field and its dynamics

In Section 2.3, the need of dynamic maps rather than static maps will be discussed. Here, the discussion is focused on the applicability of dynamic maps. In view of the question of '*what does a map show?*' we should also deal with the question '*what do the changes in a dynamic map show?*' Before the field dynamics can be monitored, it should become clear what the starting point is or what the final point is. A dynamic map of a field shows the changing interaction of its elements. In terms or co-occurrences, a dynamic map shows the changing relations between selected elements. In order to use a map for policy-related questions, all questions discussed above, should be answered before the dynamic map can be interpreted. Otherwise, the dynamic map may, for instance, reflect the changing coverage of a database rather than the field dynamics.

In Noyons & Van Raan (1998a, see Chapter 6), it is pointed out that in a bibliometric mapping study aiming at exploring actors' activities as well as field dynamics, a structure should be generated (subdomain delineation) on the basis of one period of time (say one year *T*) and this structure (delineation) should be used to analyze other years (for instance previous years, *T-i*). In this case the most recent representation of the field becomes the point of reference. A map showing the field dynamics reveals the dynamics as related to *T*. The interpretation of the field dynamics is therefore dependent on the situation in the point of reference *T*. For instance, if the analysis of the field in year *T* identifies a subdomain *X*, which seems to be a merger of two specialties (x_1 and x_2), a dynamic map based on the structure of *T*, does not notify the fusion of x_1 and x_2 into *X* as such. It does however reveal the dynamics of *X* as if it existed already in *T-i*. This approach reveals the dynamics of *X* within the whole field as defined by the 'present' (*T*) situation. It should be noted that the fusion of x_1 and x_2 into *X* is already a fact and from a policy point of view it does not seem to make sense to evaluate into detail that this merging has taken place. But it *does* seem to make sense to explore the dynamics of *X* from the present point of reference: who was responsible for the development of *X*. By retrieving the actors from *X* in *T-i*, the founding actors of *X* are revealed. In other words, this type of approach is essential in studies to 'trace' developments in scientific knowledge.

From an *historical* point of view it may make more sense to monitor the field evolution with a *past* situation as a point of reference. This approach is appropriate to show how developments in the past 'disappeared' or 'exploded' in recent time.

2.2 Co-word analysis as a bibliometric tool

Co-word analysis concerns co-occurrence analysis of specific words. These words are retrieved from publications. Every publication can be described by words. Often it makes sense to use phrases rather than single words. These phrases are (meaningful) groups of words. Together, the meaningful words and phrases are referred to as *keywords*. They describe the main issues of a publication. These keywords are available in documents in bibliographical databases. They may be 'uncontrolled', i.e., extracted from free text fields (titles, abstracts), they may be added by authors (author keywords), and they may be 'controlled', i.e., added to the publications by the database producer (indexed, thesaurus, or controlled terms). We already discussed that each type has its advantages and disadvantages (see Healey, Rothman and Hoch, 1986; Whittaker, 1989, and section 2.1). The non-indexed keywords extracted from titles and abstracts are preferable, as they can be extracted from almost every bibliographic database. This makes them more generally available and thus flexible and better adjustable to the policy issue addressed. If, for example, a field is perfectly covered by a specific database, a mapping study based on co-word analysis can always be performed, whereas in only a limited number of cases cited reference data or controlled terms are available. Moreover, with co-word analysis of 'free text'-extracted (uncontrolled) terms, different bibliographic databases can be combined.

As a result from the discussion in the previous and in the present section, we discern two kinds of keywords. The first is the keyword that describes together the contents of a *publication* and in combination with all other keywords of a publication, it discriminates one publication from the other. We will refer to this kind of keyword as being a *publication keyword* (PKW). The second type is the one describing the contents of a *publication collection* or database and will be referred to as being a *field keyword* (FKW). Together with all other FKWs it discriminates one science field from the other.

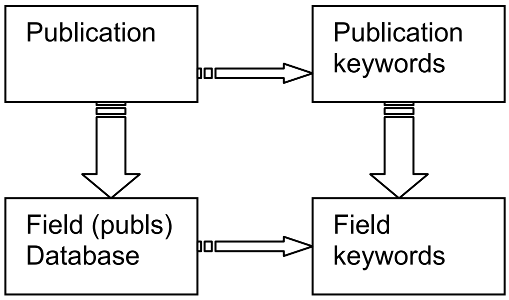

Figure 2-1 Publication keywords (PKW) and field keywords (FKW)

2.3 Mapping as a bibliometric tool

As we discussed earlier, the enthusiasm for bibliometric maps (or co-citation/co-word modeling) in the seventies and eighties has been tempered since the early nineties. Reasons for this might have been the high costs involved, the modest validity according to the experts evaluating the results, and the inaccessibility of the method and results (the maps). If we consider the three parties involved in quantitative policy-oriented studies of science (see Chapter 3), we identify at the same time three aspects to which *objections* to mapping are directed.

1. Evaluated scientists (as objects): the results;
2. Scientometricians (as producers): the data and methods;
3. Policy makers (as users): the utility.

The first objection points at the lack of recognition by researchers in the field. In particular co-word mapping has suffered from this (Healey, Rothman, and Hoch, 1986). Rip (1997) states that co-word maps are sometimes hard to understand. They would show 'pathways' rather than a structure.

> A similar kind of aggregation would occur naturally when research group leaders would report on the state of the field and ongoing and future work of their groups in relation to it. Co-word maps are thus suitable to purposes of tracing connections and locating work strategically.
>
> (Rip 1997, p. 17)

This passage particularly points out the utility of co-word maps for research evaluation or monitoring. In tat sense, one may wonder whether 'pathways' differ from, (or are inferior to) a structure. Moreover, Rip pleads for the independence of scientometrics where the results are concerned (see also Chapter 3). Once *data* and *method* have been validated, the resulting maps show a *point representation* (see section 3.2) of the field, i.e., a representation generated by the creator (the scientometrician) on the basis of approved data and method, and as such robust. It will depend on the expert, evaluating/validating the results, whether the structure is 'recognized'. It is, however, important to notice that the validation of *data* and *method* often comes down to the validation of *results*, the generated maps. As a result, the first and second objection are closely related. In view of this, we conducted a mapping study of the field in which scientometricians are active, scientometrics, informetrics, and bibliometrics (SIB). In Chapter 10, we report the method and results as well as the comments of field experts.

As to the third objection, we refer to section 3.2. Furthermore, we address the issue of the utility of a map as a representation of a science field. *Why would we create maps?* What does the spatial (positional) information add to the information we already have by distributing publications over identified subdomains. A map puts the subdomains in a two or three dimensional space in such a way that the subdomains that share many publications are in each others vicinity, and those who share few or no publication, are distant from each other. We experienced in several studies that users of our results, focus merely on the *division* into subfields, rather than on the added and typical 'mapping' information of the *positioning* of the identified subdomains. They evaluate the structure first without using the positional information. In such cases, characteristics of each subfield are compared to those of the others. For instance, by comparing the activity of actors (countries, institutes, departments) in the identified subfields, strengths and weaknesses in terms of activity of an actor can be determined. In the study presented in Chapter 9, we visualized the activity patterns of four departments of a research institute within the mapped structure of the field concerned. It appeared that the formal institutional structure with different research departments nicely fitted into the structure of the field as obtained by co-occurrence analysis. We observed that, next to the identification of subfields, the two dimensional positioning accounts to a large extend for the activity profile of each department within the institution. Thus, also the positioning on the map appears to be a valid indicator.

2.4 Science mapping as a policy supportive tool

A map of science represents the (static) situation of a field in a particular period of time, using the publication data in that time span. Often the need of validation of the map is expressed (Moed, 1989; Bauin et al., 1991; Tijssen, 1992; Hinze, 1997). In any evaluative study, the results should be checked by experts in the field, at the least to preclude accidental errors.

Once experts have expressed their contentedness with a map of their science field, regarding the structure on the basis of keyword clusters, it is still the question what to do with this information. The identification of clusters of words as subdomains (or 'themes', c.f., Callon, Law and Rip, 1986) as such could be sufficient to generate tables in order to evaluate the activity of a specific actor in the field and to compare it to other actors. The positioning of these subdomains in a two or three dimensional space is disputable as to add no valuable information, regarding its utility. In other words: *what can we do with this information*?

An analogous situation exists for weather reports on television. Some years ago, the illustration of the weather of 'today' was not more than a map of the country or region with clouds, sun and indicators for high and low pressure areas. The map showing the situation of today's weather caused the audience (user) to lose interest because most of the information referred to something they already knew. (*I know that there are clouds above the area I live, because I've seen that and it is has been raining the whole day*). Recently, these static maps have been replaced by animated maps. They show how the situation in the sky has evolved from the situation of, say, the day before. Thus, the map showing the 'final' situation is the same as the static map, but we now have more insight in how the situation has evolved to the present, thus allowing us to make, in a way, our own personal view on how things might be in the near future. For instance, with the presumption that the movements of clouds and high/low pressure areas will be continued, we are able to make our own weather forecast. On the other hand, it gives the weather forecast on television more credit, because we see how clouds sometimes move in unexpected directions.

When mapping a science field, we find ourselves in a similar position. The comments to static maps of the present are often similar to the comments to static weather report maps (*I know that these are the main areas within the field, and I know that the area I'm working in is small because ...*). The policy user of such maps may say that the maps looks nice (the expert said so) but what can he do with the spatial information. Subdomain *x* is in the vicinity of *y* but what does this tell hem about the relation of *x* and *y* besides the cognitive. By showing how the field (map) has evolved to the present situation[3], the user can put this *relation* between *x* and *y* in perspective of its evolution. The *relation* is evolving in a certain direction, and does this indicate a particular development to be expected in the near future (e.g., merger of *x* and *y* or further separation)

Whether an extrapolation of certain trends will become true remains, of course, to be seen.

[3] Films of such evolutions are available at http://sahara.fsw.leidenuniv.nl.

2.5 From scientific output to science maps

The 'process' from scientific output to science maps has been described along the lines of some basic (bibliometric) principles. Moreover, it has been pointed out how these principles could be implemented in order to create science maps that can be used for certain policy-related issues. The process as far as been discussed in this chapter is depicted in the next Figure.

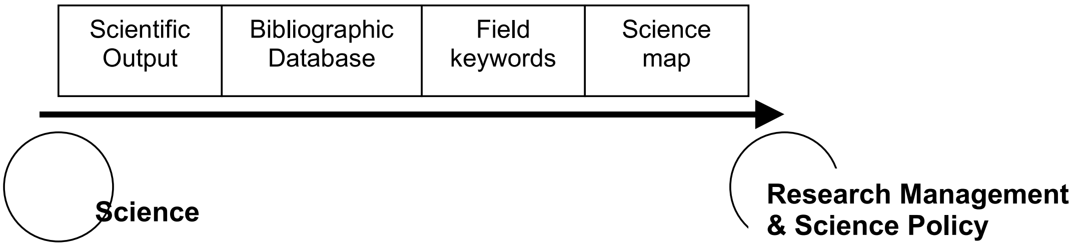

Figure 2-2 From scientific output to science maps

Furthermore, if we take into account the required utility of science map, the 'end product' should not be 'just a map' but rather a *map interface*. The interface discloses by automated procedures (e.g., via graphical internet browsers), all kinds of information 'behind' the map, such as actors, detail maps and field dynamics. Primarily, the policy-related issue raised will determine the contents and design of the map interface.

The process from publication (bibliographic) database representing a science field, to the map interface to be used to address the raised policy-related issue would look like:

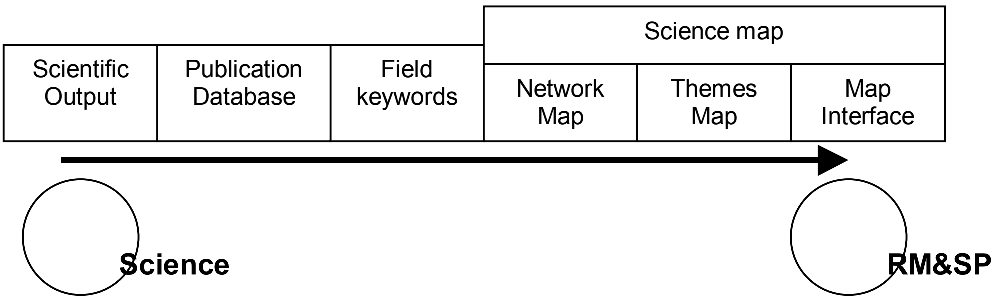

Figure 2-3 From scientific output to map interface

The transition from network map to themes map (see Figure 1-1) is one-on-one. The themes map is a simplification of the network map. As a result the former contains the information of identified subdomains .

In this chapter of principles of science mapping as a policy supportive tool have been discussed. The bottom line is that the issue to be addressed to a great extent determines the data to be used. Furthermore, it has been argued that in particular the dynamics (evolution) adds great value to the utility of science maps.

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3 Validation of science maps

The utility of a science map (for science policy support) and its evolution depends a great deal on the recognition on the one hand. The generated map should in some way refer to the 'real' situation. If not the policy relevance is unclear. Political decisions affect the actual situation, so that the map to be used to, for instance, evaluate the actual situation should be recognized as a representation. On the other hand, an 'appropriate' representation of the research field is not enough. In order to be a supportive tool to address policy-related issues, the structure (the map itself) is not enough. Then, the retrievable information as well as the way this information is disclosed plays an important role. Therefore, user validation is of vital importance. It appears that this validation has only scarcely been applied, let alone been developed as a standard procedure.

3.1 Validation of science maps by field experts

The expert validation of a generated science field map is of vital importance for the utility of a mapping study. In order to get the most out of this validation, there are three aspects to be taken in consideration: the *selection* of experts, the way they are *addressed*, and the way the results are *presented*.

Selecting experts

The first concern is to find the appropriate experts in the field under study. The aim of a mapping study determines the profile of the experts. The validation of a map based on co-author relations, aiming at unraveling the collaborative linkages structure of a field, requires an expert who is acquainted with the social structure of the field, rather than with the cognitive structure. Or, if the study does not go into the details of the field but rather is directed at an overall structure, the expert should have an extensive, 'broad' knowledge of the overall structure of the field. The detailed knowledge of subfields is of less importance. It has been experienced that in certain fields the experts with such an overall view are hard to find. In Bauin et al. (1991) a mail survey to validate obtained mapping structures failed because the addressed researchers in the studied field appeared to be too specialized to be able to sufficiently overview the whole field. Moreover, the presentation of the results of mapping study is 'unconventional', as compared to 'normal', textual descriptions. Thus, the addressed expert should be acquainted or at least feel 'comfortable' with it before he is willing to co-operate.

Addressing the expert

Once an expert is found with the right profile in view of the aims of the study, it is important to address him or her in the proper way. It should be considered beforehand what is expected from him or her. It takes *useful questions* to get *useful answers*. Bluntly proposing the generated structure, asking whether this is the right representation of the field sustains the paradox of Healey, Rothman and Hoch (1986), with respect to the utility of experts' comments.

> A paradox exists in the validation of science policy indicators. If the results are counterintuitive to experts they are considered invalid; if the same as their usual intuitions, they are considered valid but uninteresting – they reveal only that which is already known.
>
> (Healey, Rothman and Hoch 1986, p. 247)

A bibliometric map is a unique representation of a research field, without any specific convention beforehand. An unprepared expert is thus prompted with a representation of his or her field like a normal person with a map of the sewerage of his city (which can be quite 'counterintuitive') instead the well-known of the streets (which corresponds well with 'intuition'). The street map may be rejected, because the user, quite familiar with the city, does not need it. In the latter case of the sewerage system map, it may be rejected because it does not seem 'to make sense'. However, if the utility of the maps has been explained, he may become interested. Notwithstanding the familiarity with the city, the street map may disclose information on a detailed level regarding changed traffic circulation in less familiar parts of the city. The sewerage map may provide information regarding the rebuilding of his own house.

Another way in which the expert may be annoyed is expressed in the reaction (Winterhager, 1998): *Who do you think you are, claiming you can map* ***my*** *research field?* In order to attract and hold on to the expert's attention and enthusiasm, it is important to know precisely and subsequently focus on *what* specific information is presented by the maps and additional tools. The contents should refer to the expert's perception and knowledge of the field and its actors. Moreover, the *way* in which the information is presented is of vital importance. First, experts should be introduced properly into the matter, but should not be 'overwhelmed' by details about the data and methods if they are not interested. Second, the potential use of the map for the expert himself should be emphasized.

Finally, the actual presentation is important. Apart from the 'aesthetic' aspect (quality of presentation), the *interactivity* will attract users. Maps presented on a computer screen as opposed to those on paper, can be made clickable. Hence, the information 'behind' the map can (optionally) be disclosed. Thus, the 'black box' character of science maps is dealt with.

Presentation

A science map is a visual representation of a structure of a science field. This makes it an outstanding interactive tool on a computer screen. On the one hand it enables a user or expert to focus on areas of interest, without being overwhelmed by all other information included in a mapping study. On the other hand, it enables a user or expert to get information on a detailed level. If one is interested he can 'click on' to the building blocks of a map (the individual publications).

In 1996, CWTS started to develop digital maps in stead of maps on paper, in particular for the above reasons. The maps are retrievable and clickable in a HTML environment. It was a principle choice to develop them in this environment rather than in an application-specific environment (i.e., where the interactive maps are included in a specific software package), in order to assure general accessibility. Once the analyses have been conducted, the results are copied to a World Wide Web server so that in principle any person in the world with an Internet connection and a graphical web browser has access to these results. As the expert or user can give comments or ask questions immediately (for instance by e-mail), the validation can be performed during the analyses, rather than afterwards.

3.2 Kinds of validation

> Co-citation maps have been put forward as a basis for early indicators, but their foundation on citations to the literature introduces a retrospective bias. Co-word maps reflect the structure of the research front directly, but the difficulty in interpreting them has made their strategic use a promise, rather than an accomplishment.
>
> (Rip 1988, p. 256)

The validation of the obtained structure of a research field, is of vital importance for science mapping as a policy-supportive tool. In order to use the map and additional information for policy decisions and discussions, the obtained structure should refer to the 'real world'. It should be applicable to address topical policy questions and issues. In the previous chapter (section 2.1), it has been discussed how complex this reference can be. Yet, the expert, who is most likely a (senior) researcher, is not the only one involved in the validation procedure.

Rip (1997) identifies three parties to be involved in evaluative studies of science:

1. Science (scientists);
2. Science policy (policy makers);
3. Scientometrics (scientometricians).

The third party adds a dimension to the configuration of Figure 1-1. The three parties can be arranged in a triangle (Rip, 1997 calls it the 'eternal triangle') with at least two linkages where validation of the bibliometric maps are concerned. Healey, Rothman and Hoch (1986) introduced the integration of both 'internal' and 'external' validation of maps of science. The internal validation is aimed at the *structure as a representation* of the field, the external validation at the *utility* of the map as a policy supportive tool.

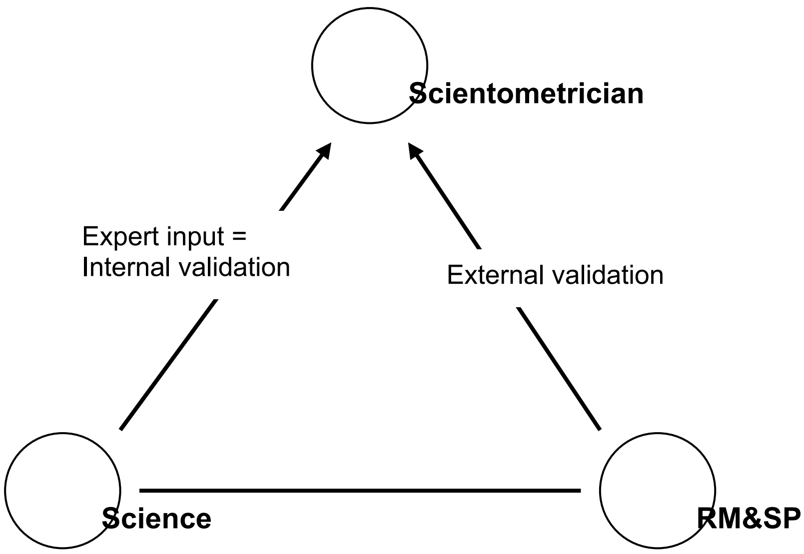

Figure 3-1 Visualization of Rip's 'eternal' triangle of scientometric evaluation, combined with the positioning of internal and external validation

In view of the validation of science maps (the scientometrician) only the relations with science and RM&SP are discussed here. The expert input (internal validation) can be used at different stages of the mapping analysis. Before the data is collected, the expert may provide information about which database to use, or which keywords to delineate the field. At the stage of the keyword selection for co-word analysis, the expert may provide input in suggesting essential keywords. This input will prevent words to affect the structure for reasons not so obvious to the scientometrician. This issue will be discussed further in Chapter 11. An other stage is when the analysis is finished and the results are available. Here, the expert input may provide information about the validity of the map. The maps and additional information are evaluated as being a 'valid' representation of the science field under study. All this concerns internal validation. To be more precise analytically, Rip (1997) identifies two kinds of *internal* validation: *extrinsic* and *intrinsic* validation. The former is a validation of the results by *field experts*, the latter is a validation of the data and method, aiming at robustness. Moreover, *intrinsic* validation links up with the *use* of the results, and thus with the external validation. The key in this linkage is 'point representation'. This term, borrowed from actor-network theory, points out that the result (the maps and indicators) is a representation not necessarily mirroring the 'real world' but rather the world as defined by the creator, and methodologically robust. In that sense, a co-word map of a field is no more but also no less than that: a specific representation of a science field, as defined (delineated) by publications from a certain database, on the basis of co-occurrences of most frequently used words (core topics in that field). Once there is an agreement on the utility of such representations for answering questions about the field (external validation), these representations can be used. The intrinsic validation accounts for robust data, method and translation of addressed issues and (bibliometric) results. In that case, Rip argues, an internal extrinsic validation is not always needed. As noted before, however, the utility of a map depends a great deal on the reference to the 'real world'. In other words, the external validation of a science map is to a great extent depending on the (extrinsic) internal validation. This validation is established by the input of field experts. As a result, the extrinsic internal validation is *inevitable*.

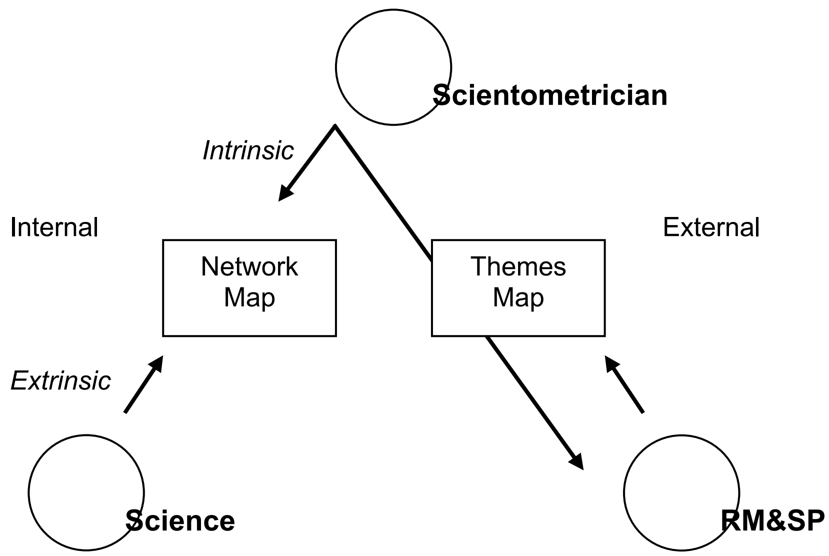

Figure 3-2 Schematic labeling of different kinds of validation

In view of the *types* of maps to be used for either internal or external validation, the network and themes map (c.f., section 2.5) are included in the scheme as well. These two map types maintain a direct relation in the sense that the themes map is directly derived from the network map.

A most important study using a combination of intrinsic validation and extrinsic validation is presented in Braam, Moed and Van Raan (1991). In that study, a generated co-citation structure is validated by analyzing the keywords in the citing articles (research front) on the basis of intra-cluster coherence, inter-cluster difference of research topics. In this approach external information (i.e., this information that did not *directly* contribute to the structure), is added to the map.

In his triangle Rip (1997) notes both productive interactions and tensions between the parties. The interactive productivity opposes to the lack of *user-pull*, noted by Tijssen (1992).

> … However, the use and appreciation of maps is still in its infancy as far as its applications in practical issues of science policy are concerned. Maps may prove a powerful aid for R&D managers and S&T policy makers in order to obtain a sense of the state and developments of scientific areas, for purposes of science policy decisions, research management and corporate planning. In this domain, the increasing sophistication of maps is still more a matter of developer-push than user-pull.
>
> (Tijssen 1992, p. 34)

This lack may have caused part of the tension and it seems exactly *this* aspect that has blocked science mapping in the past decade. The articles reporting of validation of science mapping results refer almost exclusively to the internal validation. Only two (!) out of thirteen case studies in the late eighties and early nineties are provided with a validation round, included external validation[4]. In other words, only two of these studies were evaluated by the policy-related user, who was in most cases the funding institution. In almost all thirteen studies, experts provided internal validation, by agreeing upon (most of) the structure.

As noted before, this internal validation is important, but for a policy supportive tool external validation is equally important. In Bauin et al. (1991), an extensive attempt is made to supply science maps with both internal and external validation. The need for this approach is expressed in the following.

> The problem with this purchase/supply relationships is that often the supplier is unaware of the use to which his or her study has been put. Having developed a series of indicators, the feedback that is necessary in order to improve upon them and bring them closer into line with the needs of decision-makers is often not forthcoming.
>
> (Bauin et al. 1991, p. 113)

---

[4] These studies have been reported in Healey, Rothman and Hoch (1986), Oberski (1988), Turner et al. (1988), Franklin and Johnston (1988), Law et al. (1988), Bauin et al. (1991), Braam (1991, 2 studies), and Tijssen (1992), Peters and Van Raan (1993). In the studies reported by Bauin (1991), Franklin and Johnston (1988), and Healey, Rothman and Hoch (1986) utility aspects raised by the policy related users were discussed.

Both Tijssen (1992) and Bauin et al. (1991) refer to science mapping as a policy supportive tool as being in its *infancy*, and in view of the lack of reported user input since then in these kind of studies, we must conclude that it still is.

The way in which science mapping development would benefit from utility fits well into the present research policy. Van Steen (1995) pointed out the utility of science and technology (S&T) indicators for research policy, on the condition that the policy (user) input is improved, and that the researcher and user have a good relationship, in terms of communication. In Simpson and Craig (1997), an emerging model for scientific inquiry is sketched in which the intellectual agenda is set by *strategic relevance* rather than *scientific curiosity*.

With respect to this introduction of users in order to improve validity and utility of science maps, the points made in section 2.1 (*What do maps show?*) should be taken into consideration. The utility-related comments reported in the studies listed in section 1.3 indicate that the user input has been rather 'non-committal' and in most cases retrieved after the study was conducted. This input should, however, be used before and during the study is conducted. Moreover, the input should be directed at each principle listed in 2.1. The issue(s) raised by the user as to which the study is applied, should be discussed beforehand on the basis of the listed principles of science mapping. For instance, it should be determined through discussion with the field expert whether the issue can be addressed bibliometrically on the basis of *research output*. Then, it should be discussed in detail which *database* should be used, as well as which part of the *publication* database in relation to the issue to which the map is applied. In view of the dynamic part science mapping, an answer should be given to the question whether mapping is the appropriate tool. If field dynamics does not play a role, one may wonder whether the map should be created. In cases, it may suffice to generate a structure, in terms of identifying clusters of keywords representing subdomains (themes, areas of interest) within the field. The two dimensional representation may be a 'good looking' interface for some, for others this representation is incomprehensible and therefore useless.

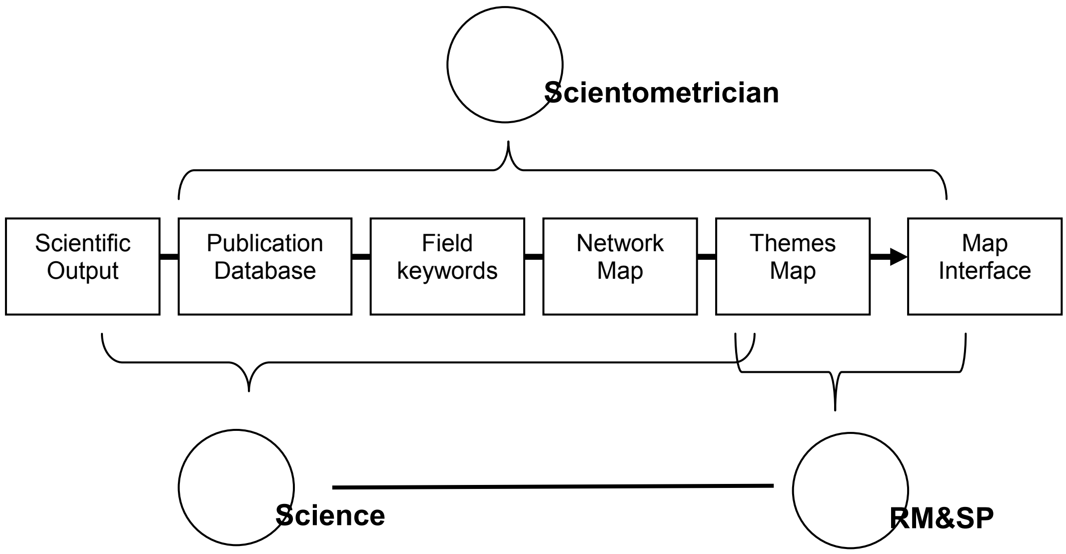

Figure 3-3 Schematic view on the validation process in relation to the mapping procedure

In Figure 3-3, the whole process from database the interactive map is integrated in the validation scope of the field expert (internal) on the one hand, and the policy-related user (external) on the other. The internal intrinsic validation covers the whole process from database to map interface, as the scientometrician is responsible for the reliability and utility of the 'product'. The internal extrinsic validation covers the range from database to at least the network map. The external validation covers the themes map and the therefrom derived map interface, in terms of utility in view of the policy-related issue addressed.

In this chapter, the validation process has been discussed in detail and is attached to the procedure of science mapping for policy-related issues. By channeling the validation into the specific steps, the quality and utility of the input necessary for validation will be improved.

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Part II Published Articles

In this part of the book, six articles published in the recent past are presented. They contribute to the discussion on science mapping as a policy supportive tool. Each article is included in the discussion for particular aspects (Chapters 4 to 9). Together, they build an overview of the activity at CWTS in the past few years regarding the development of S&T maps for policy supportive objectives. In Chapter 10, the path is sketched which CWTS is following at present.

In Chapter 4, the possibilities of *internal intrinsic* validation (See Figure 3-2) of structures based on quantitative data are discussed. Although no maps were involved in this study, it shows the strengths of this kind of validation. In the field of 'lasers in medicine', a structure is generated on a very specific basis: patent to publication citing patterns. The structure reflects the appliedness of parts of the field represented by patent applications. In general, the hypothesis that the number of citations to scientific literature indicates the 'science intensity' of patents is tested by investigating the characteristics of the scientific literature published by the patents' inventors. In the study, we found that in 'lasers in medicine', the number of cited scientific publications correlates to the 'science intensity' of patents, as measured by the character of the journals the inventor use for their publications. The main point made in this study, in view of the present discussion, is that a structure based on one particular characteristic (citations in *patents*) is validated by other data (scientific *publications* of the inventors). By including a validation established by experts, the structure is validated as well.

In Chapter 5, a basic mapping study is presented. In this study, we integrated both scientific publication data and technological patent data into a science-technology interaction evaluation of the field 'optomechatronics'. The study explores the possibilities of using data from both sides. One of the 'methodological' outcomes was that patent law may influence the results a great deal. In the studied field, we found a quite large subfield (*control/software engineering*), which was represented on the science map, but not on the technology map. The reason is that software is difficult to be patented under the European patent law. This does, of course, not mean that there is no technological activity in this part of the field. These outcomes show the importance of selecting the proper data (base) in view of the issue to be addressed, as well as the need for expert validation of the used data.

In Chapter 6, the basics of the present mapping procedures are presented. The study focuses mainly on an important issue concerning the contrast of the actor analysis on the one hand and analysis of field dynamics on the other. The evaluation of actor activity dictates a certain rigid structure during the period under study in order to fix more or less the definition of the field structure, whereas a visualization of the dynamics of a field is hindered by this rigid structure. In this contribution, we propose a method to fuse these clashing interests. Furthermore, we introduce the concept and application of 'multi-level' maps. This aspect, together with the insertion of map-external information directly in the maps, considerably improves the applicability of bibliometric maps for policy-supportive aims.

In Chapter 7, an extensive actor analysis is presented based on the method presented in Chapter 6. The article presents the results in view of 'virtual' policy issues.

The study in Chapter 8, like the work presented in Chapter 4, does not include a mapping study as such, but rather an evaluation of research in information technology (IT), where the structure of the field is based on the views of experts. The study was performed for the Flemish Ministry and aimed at identifying the main developments in IT and at characterizing the activity of Flanders in this field. An important practical issue arose from the study. The procedure, applied to provide a field structure on the basis of IT experts beforehand, appeared to be rather complex. The organization providing IT experts, suggested a structure of the field. This structure definition was translated into sets of field specific classification codes. Each set of codes represented an IT subfield. Publications and patents were collected per subfield, on the basis of the codes. But during the process, the conclusion was drawn that a most important 'subfield' had been 'forgotten' by the experts. Once the publications in this subfield were added to the database, we found this particular subfield to be the most important one for the Flemish IT. This should illustrate that the application of expert input is a delicate matter. Although the integrity of the experts is not at stake, one may question the objectivity of the delineation procedure. A selection procedure on the basis of bibliometric principles and a structure on the basis of the mapping procedures, may have led to a similar conclusion, but then the results would be more 'objective'.

In Chapter 9, the internal intrinsic validation (see Figure 3-2) of the 'micro-electronics' map is illustrated. The structure based on classification co-occurrences is enhanced with all kinds of map-external statistics. This means that the statistics are based on data that were not directly responsible for the structure of the map. For instance, statistics of actor activities or publication sources (journals, conferences proceedings) are expected to show preferences of these sources for certain parts in the map. These statistics validated the structure to be relevant. The study also shows that the paper version of these mapping studies is not appropriate for practical use. Each information item included in a publication may be of interest for validation. Moreover, a user may have a variety of interests concerning the added information items. In order to provide all this information, we need a map for each information item with a reference system (to the proper information source and page) and piles of papers containing this information per subdomain. Browsing through these piles of papers rather frustrate the user than encourage or inspire him. For large amounts of publications this browsing for many information items becomes virtually impossible, or at least completely impractical. The digital version is in that respect an excellent alternative. The user can pick out his/her areas of interest directly without being confronted with all the other information.

4 Exploring the Science and Technology Interface: Inventor-Author Relations in Laser Medicine Research*

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Exploring the Science and Technology Interface: Inventor-Author Relations in Laser Medicine Research

Abstract

The aim of this study is to investigate a specific aspect of the science and technology interface: inventor-author relations. The subject area is application of lasers in medicine. The empirical material consists of a set of 30 patents, representing the 'technology side', and 1057 publications authored by the inventors, representing the 'science side' of lasers in medicine.

Our study includes four different approaches. First, we tried to find evidence, by looking at the scientific part, for the claim that references in patents to non-patent literature (NPL references, mostly scientific publications) indicate 'science intensity'. It appeared that inventors of patents with many NPL references did not publish significantly more in science than inventors of patents with few NPL references. The former did, however, use more basic scientific journals to publish in than the latter.

Second, we tried to identify at the science side one paper per patent which would best represent the R&D activities related to the patent. Here, a weak correlation was found between the number of NPL references in the patents and the number of references in their scientific counterparts.

In our third approach, we compared the number of NPL references in the patents with expert assessments about the science intensity of each individual patent. Moreover, other aspects were taken in consideration, such as legal status of a patent (number of claims), complexity of the invention (number of pages), size of the inventor team. We found out that some of these other aspects could be related to a higher number of NPL references in patents.

In the fourth and final approach of the study, we analyzed the inventors' publications in more detail, in particular for the period before and around the patent application date. We tested and found evidence for two hypotheses. These two hypotheses state that, in preparation of a patent application, (1) co-inventors increase their co-activity in science; and (2) companies and universities level up their co-operation.

4.1 Introduction

Science and technology constitute a complicated, heterogeneous system of activities characterized by many interrelated aspects [13]. Although, in principle, virtually all scientific (S) and all technological (T) activities might be connected in one way or another, and thus both domains of human knowledge form indeed one complex system, it is not unrealistic to hypothesize that both domains still have their own identity, characterized, however, by a specific interface region they have in common (Grupp [4]). This S&T interface is the nursery of research and development (R&D) activities, and it is undoubtedly a major driving force for the economic development of our world. Therefore, systematic investigation of this network of interrelations is of crucial importance for future R&D policy.

As research on the S&T interface is still in its exploratory stage, it is not surprising that there is hardly any thoroughly formalized and quantified evidence of 'science involvement' in innovation. The few exceptions are related to patent application examination at patent offices, in particular the search for 'prior art'. Often this 'prior art' involves earlier patent documents. However, occasionally, patent examiners document the earlier status of the subject area of invention by making references to scientific literature, and not to patent literature. If the number of such *non-patent literature* (NPL) references in patent documents is used as a measure of 'science involvement', a set of indicators can be constructed for quantifying this science involvement (Grupp and Schmoch [5,6]). Carpenter, Cooper and Narin [1] showed that US patents originating from specific 'scientific' areas of technology, contain significantly more references to the prior art which are not patent documents but mainly scientific publications. In a subsequent investigation [7] on bio-engineering, Narin and colleagues found that the 'time delay' for references to scientific literature in patents is comparable to the same in scientific publications.

Van Vianen, Moed & van Raan [15] studied chemical engineering in an international context, as well as Dutch technology as a whole, in particular chemical engineering and electrical engineering and electronics. They, too, based their work on US patents and uncovered not only valuable results on important patent citation characteristics, but also a series of methodological problems. For instance, in the US patents used, a strong language barrier works to the disadvantage of all non-English literature.

Coward and Franklin [2] also tried to establish a particular relationship between science literature and patent literature in order to determine 'cross-overs' between science and technology. The suggestion was made that the most productive processes for identifying potential profit-yielding areas of scientific research for industrial technology, involve the identification of areas in which researchers were able to produce frequently scientific publications *and* patents.

Recently, Rabeharisoa [10] studied the role of scientific articles published by inventors. She focused on the rather narrow field of French fuel cell R&D in order to assess the contents of papers as well as patents. Her case analysis illustrates the intermediate dynamic function in the science and innovation complex by pointing to the crucial role of, for instance, technical papers. Rabeharisoa's contribution clearly demonstrates that it will be an unsuccessful task to differentiate scientific from technological researchers or experts, at least in fuel cell R&D.

The aim of this study is to investigate one specific aspect of the S&T interface: *inventor-author relations*. We chose *laser applications in medicine* as our subject area. Grupp & Schmoch [6] present a discussion about this choice, together with an overview of related (sub)fields in laser R&D. Laser applications in medicine cover therapeutic as well as diagnostic instruments. It is clear that this field has strong relations with physics (in particular, applied optics) as well as with medical fields. A very important and early application of lasers in medicine concerns eye surgery. With laser-ophthalmoscopy, retinal detachments (in particular in the case of diabetes patients) are treated ('spot-welding' of the retina). One of the first publications is the work of Smart [11]. A year earlier Goldman [3] had published another biomedical application of lasers, the treatment of skin cancer. Shortly after these first medical applications, Thorp [12] foresees in his review book considerable advances in the field. And indeed, in 1985 the number of patents in laser medicine was almost an order of magnitude larger than ten years before (Grupp & Schmoch [6]). For publications we find an even stronger increase (Van Vianen & van Raan [14]). Therefore, we conclude that laser medicine R&D is a dynamic and relatively young area.

4.2 Method and Techniques

4.2.1 Main lines

The core of our empirical work is a set of 30 patent applications (European Patent Office, EPO) and in addition all publications of the inventors for the period 1980-1989, as far as covered by the Science Citation Index (SCI) of the Institute of Scientific Information (ISI). The total number of publications is 1053.

Our study includes four different approaches. First, we divide our set of 30 randomly selected patents (European Patent Office, priority years mainly 1986-1988) into three subsets according to the number of references in the patent search reports to non-patent (mostly scientific) literature ('examiner-given' NPL references; see, e.g. Grupp & Schmoch [5,6], and van Vianen, Moed, van Raan [15]). In order to investigate whether the number of NPL references in patents represents a measure of 'science intensity', we analyze for each patent general publication characteristics of the inventor-authored publications, in relation to the three NPL-based patent subsets.

The second approach is a 'refinement' of the first: we now focus, for each patent, on only one specific inventor-authored publication (if present) that can be regarded as most closely related to the subject matter of the patent. The choice was made by expert opinion. Again, for this specific type of inventor-authored publications we searched for bibliometric characteristics in relation to each of the three NPL-based patent subsets. The first and the second approach thus emphasize the background of an invention, in particular its science intensity.

Third, we study the 30 patent documents in full length. With the help of experts in the field, each patent was characterized according to its dependence on recent scientific results. Further, characteristics of the patent claims, in particular the complexity of the commercial issues to be protected, the complexity of the invention, the size of the team of inventors, as well as the multiplicity of possible applications have been investigated in relation to this dependence on recent scientific results. Again, these characterizations were analyzed in relation to the three patent subsets.

Fourth, we drop the distinction of the three NPL-based patent subsets (and, therefore, leave the relation with science intensity). We now focus again on the total oeuvre of the inventor-authors, in order to find characteristics of patent-related publications, in particular their time-dependent behavior in relation to patent priority years. Thus, this fourth approach emphasizes the scientific side of an invention. We analyzed two particular characteristics of anticipated importance: the share of university-company co-operative publications in the total amount of inventor-authored publications, and the degree of inventor co-authorship, i.e., the number of inventors per patent involved in research publications.

4.2.2 Data collection

The creation of our publication database is based on three sets of ten patents each, applied for at the EPO. The composition of a set is determined by the number of non-patent literature (NPL) references in the patents. One set contains patents with no NPL references, the second contains patents with exactly one NPL reference, and the third contains patents with more than three NPL references. Of these 30 patents, the 72 inventors' names were searched for in the 1980 to 1989 CD-ROM versions of the Science Citation Index (SCI) of the Institute for Scientific Information (ISI). Our search resulted in 1053 publications with 2006 addresses. We found that the inventors of only four of the 30 patents were not represented in the SCI. In all these four cases it concerned a patent with only one inventor. For another four patents we found only one publication of a (co-) inventor (group) in the SCI. In all other cases there were three or more publications (not necessarily authored by all inventors of a patent). Two co-inventor groups even produced more than 200 publications in the ten-year period studied.

At the level of the individual inventors, we found that 58 out of 78 inventors published at least once in a journal covered by SCI (74.4%). We emphasize that we focus on publications covered by the SCI. Therefore, in this study we do not include publications that might be covered by other databases than SCI, such as EMBASE or MEDLINE. For a more extensive and detailed study of the inventors' scientific oeuvre, the use of these databases may be of importance (Van Vianen and Van Raan [14]).

4.2.3 Details of the four different approaches

As discussed above, our study includes four approaches of analyzing the data. The first is a comparison of general characteristics of publications authored by the inventors involved in the three subsets of patents.

Our hypothesis is that the subset containing patents with the most NPL references is the most science intensive, and that this science intensity should be reflected by specific characteristics of the inventor-authored publications for each patent subset. Possible characteristics are ranking lists of the publishing authors, the affiliations of the authors, the journals selected by them, and the publication types used. The list of journals for each subset was examined in more detail by taking the nature of the journals into account. For this purpose, the 'journal level' classification by Noma [9] has been used (level 1 refers to technology-oriented applied journals, whereas level 4 represents the other side of the 'spectrum', the most basic journals). Moreover, a preliminary citation analysis has been performed for the inventors' publications (1980-1989), in order to analyze their characteristic (scientific) impact for each of the three different patent subsets and thus to validate this characteristic against the original division of the patents on the basis of the number of NPL references.

In a second approach, we analyze those publications that are probably most closely related (MCR) to the subject matter of the patents. We selected, if present, one publication per patent. We assume that these MCR publications represent the scientific counterparts of the patented inventions. We identified per patent in each set these MCR publications by comparing names of co-inventors with names of co-authors, as well as addresses of patent's applicants with affiliations of the authors, the year of patent application with publication year, and by comparing the subject matter of the patent with the title of publications. We determined for each of the three patent subsets the average number of references given in the publications and investigated whether the group of MCR publications with the highest average number of references corresponds to the subset of patents with the highest number of NPL references. Furthermore, the MCR publications were subject to a citation analysis.

In the third approach, experts in the field of laser medicine analyzed the 30 patents carefully in terms of their dependence on (basic) scientific results by studying the full patent documents. In this expert analysis important aspects of the patented invention were taken into account, such as complexity of the invention (i.e. how many claims), the size of the inventor team and the multiplicity of possible applications. With the help of these data, scores for closeness to and dependency from recent scientific results were given for each patent. We emphasize that the experts did not know about

NPL references and our grouping of the 30 patents on the basis of these NPL references.

In our fourth approach, all inventor-authored publications of the three patent subsets were taken together, and grouped again, but now according to several criteria referring to hypotheses on characteristics of inventor-authored publications.

We studied the distribution of publications closest to the patents over a ten year period (1980-1989) around the date of patent application, in order to unravel publication strategies of inventors.

We formulated two hypotheses about inventor-authored publications. To test these hypotheses, we dropped the subset division as based on the number of NPL references in the patents and adopted a new division based on bibliometric characteristics of the publications themselves. Herewith, we shifted our point of reference from patents to publications. By comparison of the distribution around the date of patent application of those publications assumed to be 'closest to the patents' with the distribution of the whole set of inventors' publications, our hypotheses were tested.

We made the following assumptions: (1) the higher the number of *co-inventors* also being co-authors of a publication, the more this publication will be *related* to the patent; (2) *cooperative* publications of universities and companies (or hospitals) indicate a higher degree of application-oriented research, indicated by patent relatedness.

In order to test the first assumption, we divided the complete set of publications into three subsets. The number of co-inventors (CI) being co-authors (CA) of a publication is indicated by the 'CICA score'. Publications of which more than 50% of the co-inventors of a patent appeared to be co-authors, are classified with CICA=1; publications with exactly 50% of the co-inventors are (co-) authors with CICA=2; and publications with less than 50% of the co-inventors as (co-) authors with CICA=3. The time trends (percentage per year) of each CICA subset was studied in a ten-year period around the date of patent application.

For the second assumption, we focus on those publications, having both a university and a company as a corporate address, indicating a co-operation of these two types of institutions (U&C). We suppose that these U&C publications are also closely related to the patents, assuming that companies in most cases are applicants of the patents concerned. Again we made a trend analysis (percentage per year) with this set of U&C publications.

4.3 Results and Discussion

4.3.1 First approach: general bibliometric characteristics

Our first approach concerns characteristics of inventor-authored publications, in particular the relation of specific characteristics with the three patent subsets, which are based on the number of NPL references in the patents. Our assumption was that the characteristics to be analyzed may indicate a relation with 'science intensity' of the patented invention, i.e., its relatedness with academic research. Our goal is to find empirical evidence in favor of or against the claim that the number of NPL references in the patents is a measure of science intensity.

More or less to our surprise, the great majority of the inventors appears to publish at least once in journals covered by the SCI. Basic data of the inventor-authored publications are given in Table 4–1. We show for each patent of the three subsets the number of inventor-authored publications, the number of inventors being authors, and the number of citations to inventor-authored publications in the (sample-) years 1983, 1985, 1987, and 1989.

Table 4–1 Number of publications (Npu), number of inventors (Nin), number of inventor being author (Nau), and number of citations (Nci)

Patent set 1 (NPL=0)					Patent set 2 (NPL=1)					Patent set 3 (NPL=3)				
Ptnr	*Npu*	*Nin*	*Nau*	*Nci*	*Patnr*	*Npu*	*Nin*	*Nau*	*Nci*	*Patnr*	*Npu*	*Nin*	*Nau*	*Nci*
1.01	6	1	1	7	2.01	0	1	0	0	3.01	0	1	0	0
1.02	8	3	2	5	2.02	1	3	3	0	3.02	3	4	1	8
1.03	23	1	1	33	2.03	20	2	2	19	3.03	17	3	3	5
1.04	16	3	2	31	2.04	15	3	2	6	3.04	12	2	2	13
1.05	17	4	4	63	2.05	1	3	1	0	3.05	13	2	2	24
1.06	37	4	3	18	2.06	56	2	2	9	3.06	216	5	4	580
1.07	5	2	1	18	2.07	269	3	3	252	3.07	16	7	3	29
1.08	0	1	0	0	2.08	139	5	5	149	3.08	16	1	1	2
1.09	3	2	1	0	2.09	1	1	1	0	3.09	1	1	1	0
1.10	59	4	4	97	2.10	0	1	0	0	3.10	83	3	3	186
	174	25	19	272		502	24	19	435		377	29	20	847

The numbers of inventor-authored publications seem to differentiate somewhat between the three sets. A closer look at the data, however, points out that the differences are primarily due to one or two teams per set. Set 2, for instance, owes its highest number of publications almost exclusively to the productivity of one group of co-inventors, namely the inventors of patent nr. 2.07. On the other hand, two groups of co-inventors in this patent set do not have any publication in SCI-covered journals (patents 2.01 and 2.10), whereas in patent set 1 only one group is found without publications covered by SCI (patent 1.08). Moreover, in patent set 1 all other nine patents have inventors who produced at least three publications, whereas in patent set 2, there are three patents with inventors who produced only one (SCI) publication. This may illustrate that these basic figures are not sufficient to bring out the possible differences between the three patent sets. Thus, mere numbers of inventor-authored publications *do not discriminate significantly* between degrees of patent science intensity, as far as this latter characteristic is measured by the number of NPL references in the patents.

Also the number of inventors being authors does not yield notable differences between the three sets. In all three sets, about 75%of the inventors (of lasers in medical applications) are authors of at least one publication covered by the SCI.

In order to find further evidence in favor of or against the presupposition (Narin et al.[8]) that the number of NPL references in patents indicates a degree of science intensity, we performed a preliminary publication citation analysis. Citations given in 1983, 1985, 1987, and 1989 (sample years) to *publications* of the inventors (1980 - 1989) of each patent were counted in the SCI (last column, Table 4–1). The overall figures show remarkable differences between the three patent sets. At first sight, patent set 3 appears to be the most 'science intensive', in terms of received citations by inventor-authored publications. Only half of that number is received by patent set 2, and just a fourth by set 1. But again, the high number of citations for patent sets 2 and 3 are primarily due to 'outliers', two inventor teams (with this we mean the inventors of one specific patent) of patents 3.06 and 3.10. In set 2, as much as five inventor teams receive no citations at all in the years included in our analysis. Those inventor teams with the most publications, also have the most citations (patents 2.07 and 2.08). If we neglect the outliers in sets 2 and 3, it becomes problematic to decide which set represent the most science intensive one, as far as it concerns received citations. It is certainly not set 2, but even set 3 shows, if we only neglect patentnr. 3.06, a less favorable 'spread' in number of citations than set 1.

Apparently, more information is required about inventor-authored publications in order to decide whether a specific patent set is more science intensive than another. Therefore, we made an analysis of further characteristics of each set. For this purpose a bibliometric profile was created for the publications of each set. These profiles have been developed as a standard bibliometric tool of the Leiden group. They contain the following information elements: (1) author names of publications; (2) corporate addresses of authors; (3) type of articles; and (4) journals used for publications.

In this study we focus on (2) and (4). In Table 4–2 we present the results for the addresses (the first 10 in ranking). Comparing the ten most frequently occurring addresses of the three sets, we could hardly find any characteristic differences. Each set has about five university addresses in its top 10. Assuming that publications with a university address should be considered as more basic research oriented, we notice that the publications in all three sets appear to have the same character. However, it should be noted that the SCI coverage tends to be less complete at the applied side of the journal spectrum, so that there might be a bias against publications with company addresses.

Table 4–2 Addresses of inventor-authored publications (Npu= number of publications)

Patent Set 1

Rank	*Npu*	*Institute*
1	29	INST OPHTHALMOL, LONDON, GREAT BRITAIN
2	22	UNIV LONDON, LONDON, GREAT BRITAIN
3	9	MESSERSCHMITT BOLKOW BLOHM GMB, MUNICH, FED REP GER
4	9	STADT KRANKENHAUS MUNCHEN, MUNICH, FED REP GER
5	9	UNIV MUNICH, MUNICH, FED REP GER
6	8	NIPPON HOSO KYOKAI, TOKYO, JAPAN
7	7	MED UNIV LUBECK, LUBECK, FED REP GER
8	6	NATL CANC CTR, TOKYO, JAPAN
9	6	UNIV CHICAGO, CHICAGO, USA
10	5	COLUMBIA UNIV, NEW YORK, USA

Patent Set 2

Rank	*Npu*	*Institute*
1	141	HARVARD UNIV, BOSTON, USA
2	89	UNIV HEIDELBERG, HEIDELBERG, FED REP GER
3	31	CORNELL UNIV, NEW YORK, USA
4	20	RIVERSIDE RES INST, NEW YORK, USA
5	16	UNIV FREIBURG, FREIBURG, FED REP GER
6	14	THOMSON CSF, PARIS, FRANCE
7	13	MAX PLANCK INST STROMUNGSFORSC, GOTTINGEN, FED REP GER
8	12	UNIV ARIZONA, TUCSON, USA
9	8	UNIV CALIF LAWRENCE LIVERMORE, LIVERMORE, USA
10	5	EUROPEAN MOLEC BIOL LAB, HEIDELBERG, FED REP GER

Patent Set 3

Rank	*Npu*	*Institute*
1	135	UNIV PENN, PHILADELPHIA, USA
2	45	TNO, RIJSWIJK, NETHERLANDS
3	18	ERASMUS UNIV, ROTTERDAM, NETHERLANDS
4	18	UNIV CALIF LAWRENCE LIVERMORE, LIVERMORE, USA
5	16	MAX PLANCK INST BIOPHYS CHEM, GOTTINGEN, FED REP GER
6	14	ALCON LABS INC, FT WORTH, USA
7	13	ONCOGEN, SEATTLE, USA
8	13	UNIV GRENOBLE 1, GRENOBLE, FRANCE
9	12	HOKKAIDO UNIV, SAPPORO, JAPAN
10	12	NEW YORK UNIV, NEW YORK, USA

Table 4–3 Journals used by inventors for publications(Npu= number of publications)

Patent Set 1

Rank	*Npu*	*Journal*
1	21	LASERS IN SURGERY AND MEDICINE
2	10	PROCEEDINGS OF THE SOCIETY OF PHOTO-OPTICAL INSTRUMENTATION ENGINEERS
3	7	EUROPEAN UROLOGY
4	6	APPLIED OPTICS
5	6	BRITISH JOURNAL OF OPHTHALMOLOGY
6	6	GASTROINTESTINAL ENDOSCOPY
7	6	JOURNAL OF THE OPTICAL SOCIETY OF AMERICA
8	5	EXPERIMENTAL EYE RESEARCH
9	5	TRANSACTIONS OF THE OPHTHALMOLOGICAL SOCIETIES OF THE UNITED KINGDOM
10	4	INVESTIGATIVE OPHTHALMOLOGY & VISUAL SCIENCE

Patent Set 2

Rank	*Npu*	*Journal*
1	79	JOURNAL OF INVESTIGATIVE DERMATOLOGY
2	50	CLINICAL RESEARCH
3	22	LASERS IN SURGERY AND MEDICINE
4	15	BERICHTE DER BUNSEN GESELLSCHAFT FUR PHYSIKALISCHE CHEMIE
5	14	HUMAN GENETICS
6	14	JOURNAL OF THE AMERICAN ACADEMY OF DERMATOLOGY
7	13	ARCHIVES OF DERMATOLOGY
8	12	AMERICAN JOURNAL OF OPHTHALMOLOGY
9	12	PHOTOCHEMISTRY AND PHOTOBIOLOGY
10	11	APPLIED PHYSICS B-PHOTOPHYSICS AND LASER CHEMISTRY

Patent Set 3

Rank	*Npu*	*Journal*
1	29	CHEMICAL PHYSICS LETTERS
2	25	JOURNAL OF CHEMICAL PHYSICS
3	21	BIOPHYSICAL JOURNAL
4	13	BIOCHEMISTRY
5	13	EXPERIMENTAL HEMATOLOGY
6	11	APPLIED OPTICS
7	11	APPLIED PHYSICS B-PHOTOPHYSICS AND LASER CHEMISTRY
8	11	CYTOMETRY
9	10	PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF THE UNITED STATES OF AMERICA
10	9	ABSTRACTS OF PAPERS OF THE AMERICAN CHEMICAL SOCIETY

So far, we must conclude that the differences in all the above analyzed characteristics between the three patent sets appear to be not significant enough to support the claim that the number of NPL references in a patent represents a measure of science intensity in one way or another.

Our bibliometric profiles, however, give us another information element: the journals (as far as covered by the SCI) in which the publications appeared. Similar to the addresses, we focused our attention to the top-10 in the ranking list for each patent set (Table 4–3).

At first sight, these rankings tend to be rather inaccessible. It is hard to judge which journal list belonging to one of the three patent sets, is more or less basic-oriented than another. Therefore, we used the 'level indicator' of journals (Noma [9]). With help of experts' judgments, a level (1 to 4) is assigned to each journal of the SCI. To mention the extreme cases, level 1 is attached to journals considered as 'very applied' or 'technology-oriented', whereas journals of level 4 are considered to have a typical basic research character. With help of this simple typology, we were able to characterize the 'basic versus applied nature' of the journals, and therefore in first approximation also of the inventor-authored publications concerned. We counted per patent set the number (frequency) of publications with a specific level. These data are represented by a frequency distribution in Figure 4-1.

The results of this analysis are quite remarkable. As illustrated by Figure 4-1, a clear shift of the frequency distribution from set 1 to 3 is visible. Whereas the inventor-authors of patent set 1 have chosen for more technologically oriented journals, the inventor-authors of set 3, use much more basic journals. The inventor-authors of set 2 are just in between. With the knowledge that patent set 1 is based on patents with no NPL references, set 2 on patents with just one, and set 3 on patents with more than three NPL references, our journal-level finding appears to be the *only* bibliometric indicator, as far as investigated in this study, *in favor* of the claim that the number of NPL references is an indicator of 'science intensity' and that therefore the patents of set 3 are the most science-intensive (i.e., the most basic research-oriented).

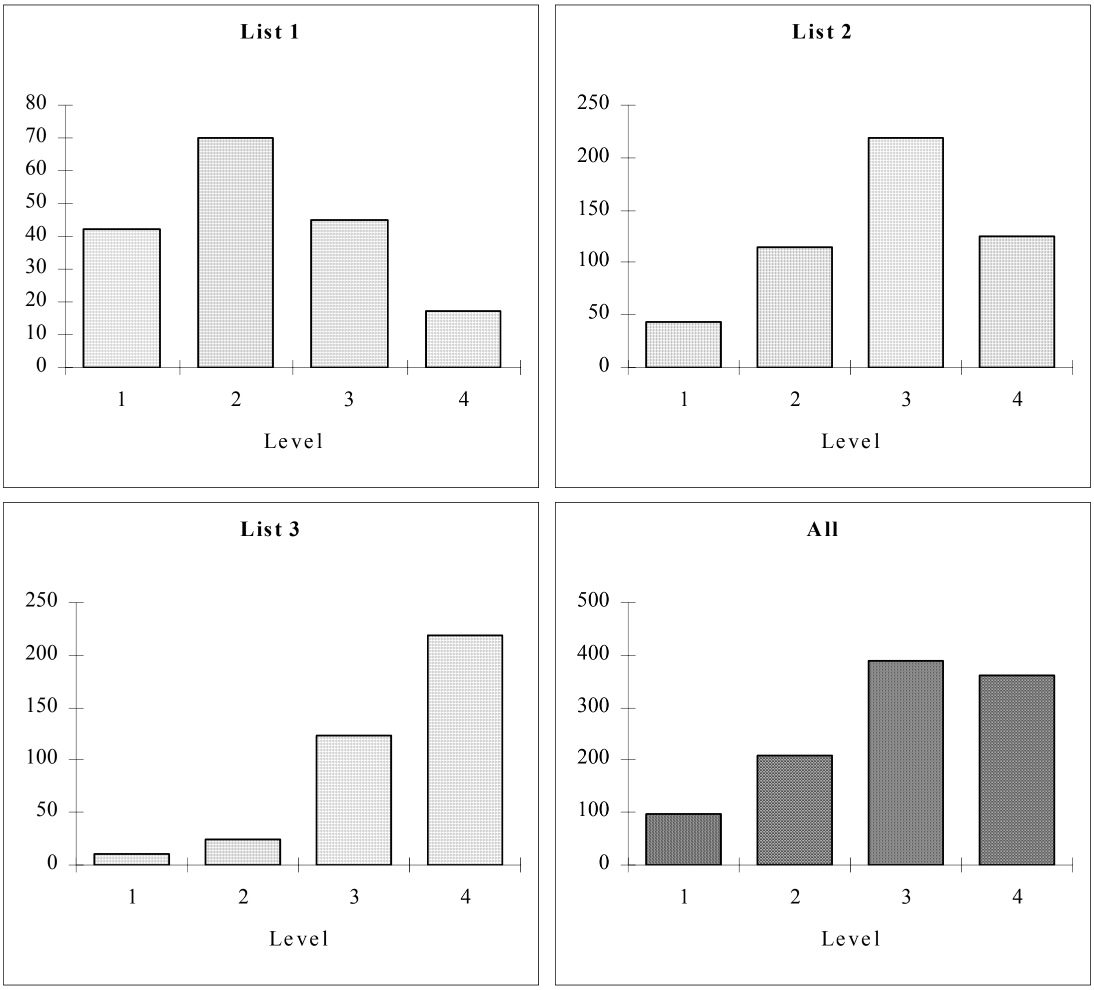

Figure 4-1 Distribution of inventor-authored publications over 4 journal levels

4.3.2 Second approach: scientific counterparts of patents

In the above discussed first approach the 'science side' of a patented invention was represented by the complete publication oeuvre of inventors (1980-1989, and as far as represented by the SCI). This approach has the disadvantage of taking all scientific activities of inventors into account, also those that are probably not (closely) related to the patented work. As we are interested in the science intensity of the particular inventions, this may be a drawback. The work leading to a patented invention may only be just part of the inventors' research activity at that time. Therefore, we tried to identify for each patent one inventor-authored publication that may be regarded as being most closely related to the patent work. In other words, we try to find a *scientific counterpart* of each patent. For 18 of the 30 patents, we identified (using expert opinions) such a most closely related (MCR) publication. We arranged these MCR publications according to the three original patent sets, and analyzed their specific characteristics.

In order to structure our analysis, we first formulate two hypotheses. The first one is that the number of references in MCR publications and the number of NPL references in the patents are highly correlated. This would imply that the average number of references of MCR publications related to patents in set 1 is significantly lower than the average number of references of MCR publications related to patent set 3. Apparently, as we can see in Table 4–4, this is indeed the case.

Table 4–4 Number of references (Nre) in MCR publications per patent (Nmcr) for each patent set

Patent set 1		*Patent set 2*		*Patent set 3*	
1.01	14	2.01	n a	3.01	n a
1.02	6	2.02	5	3.02	n a
1.03	3	2.03	n a	3.03	14
1.04	0	2.04	n a	3.04	4
1.05	7	2.05	n a	3.05	8
1.06	0	2.06	12	3.06	47
1.07	n a	2.07	18	3.07	36
1.08	n a	2.08	11	3.08	9
1.09	n a	2.09	n a	3.09	n a
1.10	20	2.10	n a	3.10	14
Nmcr	7		4		7
Nre	50		46		132
Mean	7.1		11.5		18.9
STD	6.9		4.6		15.0

In both patent sets (1 and 3), we found a MCR publication for seven patents. The average number of references in the case of set 3 is significantly higher. Moreover, in set 1, two MCR publications appeared to have no references. With respect to set 2, we found for only 4 patents a MCR publication, which may indicate a less science-intensive character than, for instance, set 1. On the other hand, these four publications have a significantly higher number of references per paper than the seven publications of set 1 (11.5 against 7.1). With respect to our first hypothesis, we must conclude that there is only a weak support for the claim that the number of NPL references indicates science intensity of patents. Our findings that set 2 only has four patents with a MCR publication against seven in both set 1 and set 3, is also not in favor of our first hypothesis.

Our second hypothesis is the assumption that science intensity of patents may be related to the scientific impact of the corresponding MCR publications. Taking into account that the application of most of the patents was relatively recent, we assessed the short-term impact, using a 'three-year' citation count window, see Table 4–5.

Table 4–5 Number of citations (Nci, three year citation-count-period) to MCR publications per patent for each patent set

Patent set 1		*Patent set 2*		*Patent set 3*	
1.01	11	2.01	n a	3.01	n a
1.02	7	2.02	2	3.02	n a
1.03	3	2.03	n a	3.03	17
1.04	0	2.04	n a	3.04	2
1.05	7	2.05	n a	3.05	8
1.06	1	2.06	5	3.06	18
1.07	n a	2.07	12	3.07	2
1.08	n a	2.08	4	3.08	3
1.09	n a	2.09	n a	3.09	n a
1.10	15	2.10	n a	3.10	3
Nmcr	7		4		7
Nre	44		23		53
Mean	6.3		5.8		7.6
STD	5.0		3.8		6.6

As compared with the results of Table 4–4, the differences between the three patent sets are even much less significant. Still, the average number of citations per MCR publication is slightly higher in set 3 than in sets 1 and 2 (7.6 against 6.3 and 5.8). This implies that the (short-term) impact of (applied) research related to patents is more or less the same for all three sets. Thus we find little support for the assumption that the science intensity of patents (as measured by the number of NPL references) is correlated to the (short-term) impact of MCR publications.

So far, the first two approaches yield the following results concerning the science intensity of patents:

(1) the *number of NPL references* in patents correlates significantly with the basic versus applied *nature of journals* used by inventors for their publications, i.e., with the type of inventor-authored publications in terms of basic versus technology-oriented research;

(2) the *number of NPL references* in patents correlates only weakly with the *number of references* in those inventor-authored publications, that are *most closely related* with the patented invention (MCR publication).

As mentioned before, it is a drawback of the first approach that the whole oeuvre (1980-1989) of inventors is included. Hence, publication characteristics may apply to an inventor primarily as a scientific author, rather than as an inventor. In the second approach, however, the selection of only one publication that can be considered as being most closely related to a patent, reduces the numbers so radically that problems with statistical significance arise. This raises the question how meaningful the distinction of the three patent sets according to the NPL references really is.

4.3.3 Third approach: expert opinions

The findings of the third approach, based on expert opinions on each patent, are as follows (the experts involved did not know about of the number of NPL references).

Table 4–6 Principle properties of patent documents and expert assessment

Patent set 1						Patent set 2					Patent set 3				
Nr	*EA*	*Ncl*	*Npg*	*Ncc*	*Nin*	*EA*	*Ncl*	*Npg*	*Ncc*	*Nin*	*EA*	*Ncl*	*Npg*	*Ncc*	*Nin*
1	1	27	7	5	1	1	14	12	2	1	3	47	11	2	1
2	3	67	26	1	3	1	15	4	5	3	5	78	17	3	4
3	1	11	6	2	1	1	9	7	2	2	3	20	6	1	3
4	2	8	9	3	3	1	6	6	2	3	1	46	14	1	2
5	1	35	11	2	4	2	7	4	2	3	1	49	14	1	2
6	1	10	4	3	4	3	21	8	3	2	5	40	24	2	5
7	1	14	4	2	2	4	11	7	1	3	1	7	9	1	7
8	3	11	4	1	1	4	3	3	4	5	4	48	27	2	1
9	1	7	3	3	2	1	6	6	2	1	1	19	10	2	1
10	3	10	15	3	4	1	10	5	1	1	3	10	6	2	3
Mean	1.7	20.0	8.9	2.5	2.5	1.9	10.2	6.2	2.4	2.4	2.7	36.4	13.8	1.7	2.9
STD	0.9	17.9	6.6	1.1	1.2	1.2	5.0	2.4	1.2	1.2	1.6	20.9	6.7	0.6	1.9

EA= expert assessment of science involvement (scale 1 to 5); Ncl= number of claims; Npg= number of pages; Ncc= number of classification codes; Nin= number of inventors; STD= standard deviation)

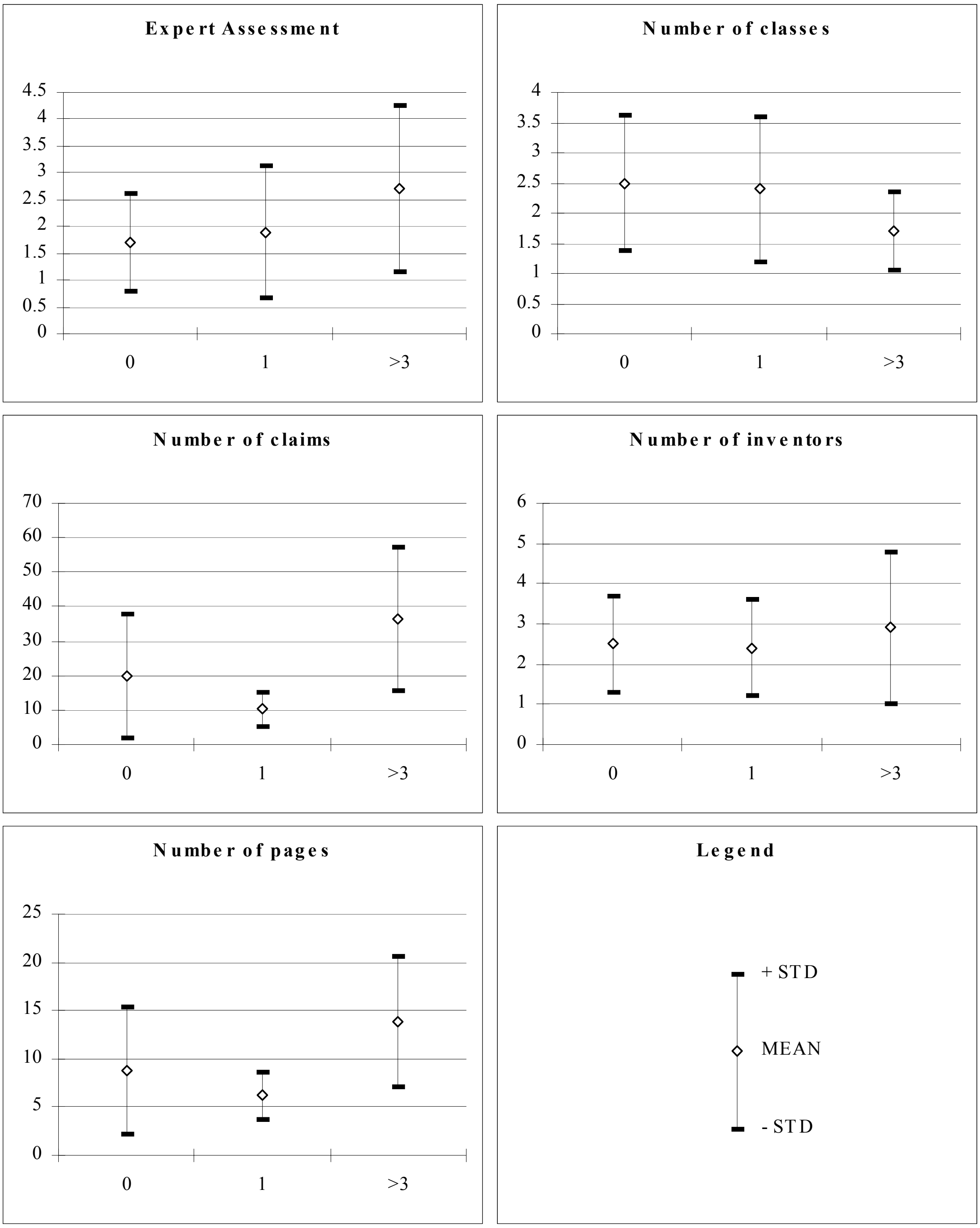

Figure 4-2 NPL-references vs. 5 other indicators

As shown in Table 4–6 and Figure 4-2, the expert assessment of the 'science involvement' of the patents correlates with the number of NPL references in the expected direction. The more NPL references patents contain, the higher the science intensity scores are. However, there is a large variance between the sets of ten patents so that the differences in experts' scores, again, are *not* significant. The large standard deviation may be due to the low number of patents in the sets, but the experts think that also a larger sample probably will not yield significant differences. The experts indicated to us that, generally, frequent resort to scientific papers is a necessity in certain patent documents for other reasons than science intensity. This remark stimulated us to investigate some other features of these patents. What are these possible other reasons? Patent examiners have to check the novelty of an invention claim by claim. If there are many claims in a patent application, then the legal situation requires that the examiners give more references to earlier patents and/or to scientific publications (i.e. proofs). Indeed, as Figure 4-2 shows, patents with more than three NPL references are characterized (with a large variance) by more claims than other patents. This means that there is another reason than only science intensity which requires more frequent NPL references. A third issue is the *complexity* of the invention which, according to the experts, can be measured by the length of the document (the description of the invention and its background). Patents with more than three NPL references appear to be longer and, according to the experts, more complex. Difficult deliberations with regard to topics such as tissue properties, radiation exposure, and 'half-width' of energy in skin, take place in laser medicine. Sometimes cumulated citations to physiology, radiation biology and cancer research are given together with those to laser or atomic physics just because the invention covers more than laser treatment of one organ or one specific application.

There are two other reasons for a patent examiner to refer in the search report of an individual patent application to scientific literature: complex contents and a complex array of legal claims. Therefore, we conclude that the whole field of laser medicine is science dependent.

The above conclusion is further supported by the observation that those patents with more than three NPL references are somewhat more central in terms of classification (i.e., multiple classification less likely; see Figure 4-2). They might be more complex in contents, more complex in legal terms and more science-intensive, but often they are classified in hierarchically higher patent classes because their specificity is not as clear as in other cases. The three sets of patents do not differ in size of inventor teams, i.e., those with more NPL references, are *not* related to larger teams.

Table 4–7 Common features of 30 patents in Lasers in Medicine

Expert assessment of science involvement	*N* *Ncl*	*N* *Npg*	*N* *Ncc*	*N* *Nin*	*NPL refs.*
Closest (*N*=5)	36.0 (27.0)	15.6 (9.3)	2.4 (1.0)	3.6 (1.5)	2.6 (1.4)
Close (*N*=9)	22.3 (19.7)	9.8 (6.5)	2.0 (0.8)	2.7 (1.1)	1.4 (1.7)
Not close (*N*=16)	17.8 (13.6)	7.6 (3.5)	2.3 (1.2)	2.3 (1.6)	1.3 (1.4)

For Ncl, Npg, etc., see legend Table 4–6. Closest: expert scores 4 and 5 in Table 4–6; Close: expert scores 2 and 3; Not close: expert score 1 (standard deviations between parentheses).

Table 4–7 presents an 'inverted view'. Here we re-group the 30 patents according to the expert scores for science intensity: one set with patents scoring 1, another set scoring 2 or 3, and a third set scoring 4 or 5. Again, it is demonstrated that NPL references as well as the legal and cognitive complexities (number of claims and pages) increase with science intensity as defined by the experts. However, none of these relations is very significant, the most suggestive one being the length of the document. In this representation team size does seem to correlate with science intensity, in contrast with our findings in Table 4–6.

The above observations confirm that science intensity is an intrinsic feature of a technology field *as a whole* (Grupp and Schmoch [5], p.90) and not as much an *individual* property of a patent document within that field. Therefore, if a sample of patents contains *many* NPL references, then an individual patent in that sample with little or even without such references may nevertheless also be influenced by science, just as patents with many NPL references may have a rather remote science link (Table 4–6). Yet, patents differ by type of journal used by the inventors for their scientific publications: 'more complex' inventions with a larger number of NPL references are linked to inventor-authored publications in more basic journals, as opposed to 'less complex' inventions with no or a few NPL references. These 'less complex inventions' are related to applied or technology-oriented journals. Insofar as a journal indicates a type of research, the three original patent subsets are linked to either basic or more applied/ technology-oriented research. Still, all subsets are linked to science in general, as indicated by the extent of scientific activity of inventors and the expert assessments. We conclude that the number of NPL references seems to correlate more with *type* of research.

4.3.4 Fourth approach: time trends in inventor-author relations

4.3.4.1 Two basic indicators

In our fourth approach we return to the data set used for the first approach: the complete scientific oeuvre of inventors of 1980 - 1989 (as far as published in SCI-covered journals). We will make an attempt to develop further indicators for tracking down the inventors' publication activity period before a patent application. In this way, we eventually may be able to make a better selection from an inventor's whole oeuvre of those publications relevant to the patent.

For this analysis, our earlier identification of just one MCR publication per patent is dropped. As mentioned above, all inventors' publications are used. We hypothesize that two specific bibliometric characteristics of publications would indicate 'closeness' to patents. Based on these characteristics, the database is divided into one subset which can be regarded as a collection of publications being relatively close to the patented invention and one subset being less close, to be used as a test group. Both subsets are subject to a trend analysis over a ten-year period (1980-1989).

One additional remark must be made about the database. The priority years of the patents involved in our analysis are not the same. Most of the patents, however, have 1986 or 1987 as priority year. In order to avoid inaccuracies introduced by mixing different time trends, we restricted the data of our analysis only on the basis of patents with priority year 1985, 1986 or 1987. This reduces the number of patents to 22, and the number of publications (by inventors of the thus selected patents) to 581, with 1117 addresses.

The two specific bibliometric characteristics (in quantified form: indicators) are the following.

(1) Number of co-inventors being co-authors

This first characteristic indicating 'closeness' to a patented invention is the relative number of co-inventors being also co-authors of a publication. We divided all inventor-authored publications into three subsets, on the basis of the CICA score as discussed in Section 2.3: (1) publications with more than 50% of co-inventors as co-authors (CICA=1); (2) publications with 50% of co-inventors as co-authors (CICA=2); (3) publications with less than 50% of co-inventors as co-authors (CICA=3).

The distribution of publications in each CICA set over a period of ten years is shown in Table 4–8, smoothed per 2 years (i.e., numbers of 2 successive years are added and divided by 2) to reduce annual fluctuations. In addition, the relative activity per two-year block (i.e., the percentage of publications per block relative to the total production in the whole period) is given. Figure 4-3 shows these percentage distribution results.

Table 4–8 Publication trend per CICA-group (1980-1989)

	CICA=1		CICA=2		CICA=3		All	
Period	*N*	*%*	*N*	*%*	*N*	*%*	*N*	*%*
80-81	6.5	8.2	4.0	4.5	46.5	11.2	57.0	9.8
81-82	7.0	8.9	3.5	4.0	57.5	13.9	68.0	11.7
82-83	6.0	7.6	8.5	9.7	55.0	13.3	69.5	12.0
83-84	4.5	5.7	11.5	13.1	43.5	10.5	59.5	10.2
84-85	10.0	12.7	14.0	15.9	36.5	8.8	60.5	10.4
85-86	**12.5**	**15.8**	**15.0**	**17.0**	**46.0**	**11.1**	**73.5**	**12.7**
86-87	**13.0**	**16.5**	**11.5**	**13.1**	**44.0**	**10.6**	**68.5**	**11.8**
87-88	8.5	10.8	8.5	9.7	30.0	7.2	47.0	8.1
88-89	4.0	5.1	6.0	6.8	25.0	6.0	35.0	6.0

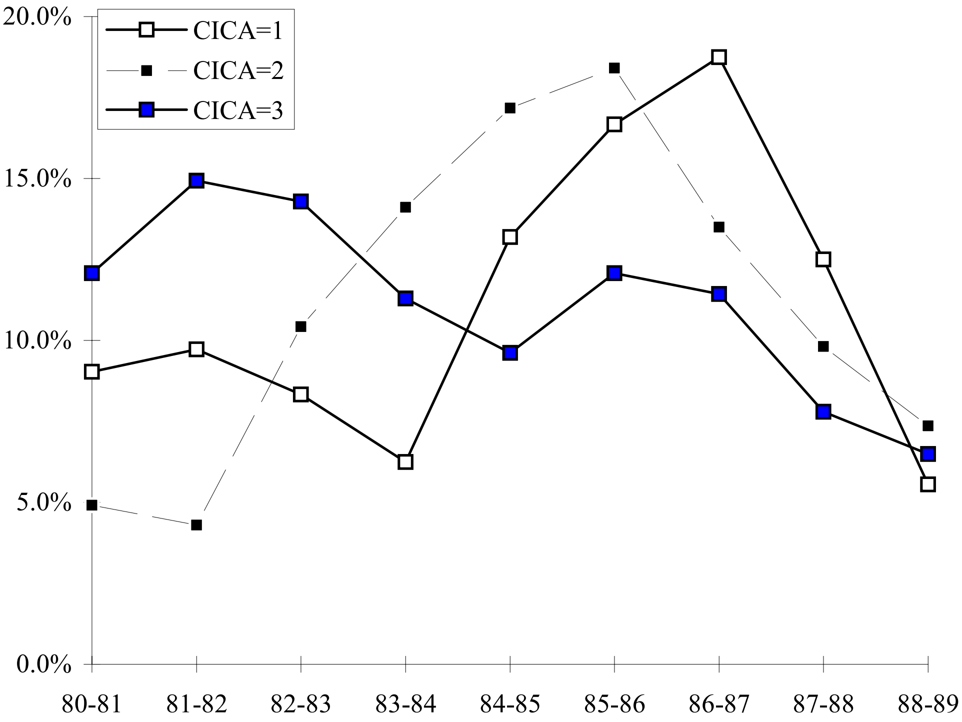

Figure 4-3 Distribution of inventor-authored publications over a 10 years period

In the sets of 'CICA=1' and 'CICA=2' publications, a significant increase of publication activity starts around 1984/1985 and 1983/1984, respectively. Afterwards (around 1986/1987), it returns to the level of before 1984. The number of 'CICA=3' publications, however, is rather stable throughout almost the whole period (around

10%), but decreases in the most recent years. The set of all publications shows the same trend.

As the activity increase of 'CICA=1' and 'CICA=2' culminates just before the year of patent application period, we may conclude that the inventor-authored publications in these subsets, indeed, are most closely related to the patent work. This would mean that around the date of patent application, co-inventors also increase their co-activities in scientific research, as far as reflected by publication numbers (in SCI-covered journals). With the above approach, we can not decide whether these inventor-written papers do reflect research activities parallel to the patent work and therefore might be characterized as the 'scientific counterparts of the patent', or cover more application-oriented research which in fact *precedes* the patent. The most plausible explanation, however, is that there is R&D activity on a specific topic in laser medicine, the work becomes successful and more and more results are published in (applied) scientific articles. Meanwhile, also technological application reaches the stage of concrete possibilities and materializes in a patent application. Thus, we choose for the 'parallel' process in which scientific and technological work go hand in hand. Nevertheless, as far as published knowledge concerned, we conclude that publication data precedes patent data.

(2) Co-operation of universities and companies

The second characteristic indicating 'closeness of publications to patents', is the co-operation of universities with companies. From the patent data, we learned that in most cases the applicant of patent is a company. On the other hand, we also found that most of the inventors are affiliated to universities. Therefore, it is interesting to investigate trends of university-company collaboration. For this analysis, we composed two new subsets of the inventor-authored publications. One subset contains publications with both a university and a company address, and the other contains all other publications. As in the previous analysis, both subsets are subject to a trend analysis over a ten- year period. The results are represented in Table 4–9 and Figure 4-4.

Table 4–9 Publication trend for university-company (U&C) co-operation (1980-1989)

	U&C		Other		All	
period	*N*	*%*	*N*	*%*	*N*	*%*
80-81	6.0	8.5	51.0	10.0	57.0	9.8
81-82	2.5	3.5	65.5	12.8	68.0	11.7
82-83	2.5	3.5	67.0	13.1	69.5	12.0
83-84	5.0	7.0	54.5	10.7	59.5	10.2
84-85	7.0	9.9	53.5	10.5	60.5	10.4
85-86	**10.0**	**14.1**	**63.5**	**12.5**	**73.5**	**12.7**
86-87	**13.0**	**18.3**	**55.5**	**10.9**	**68.5**	**11.8**
87-88	10.0	14.1	37.0	7.3	47.0	8.1
88-89	7.0	9.9	28.0	5.5	35.0	6.0

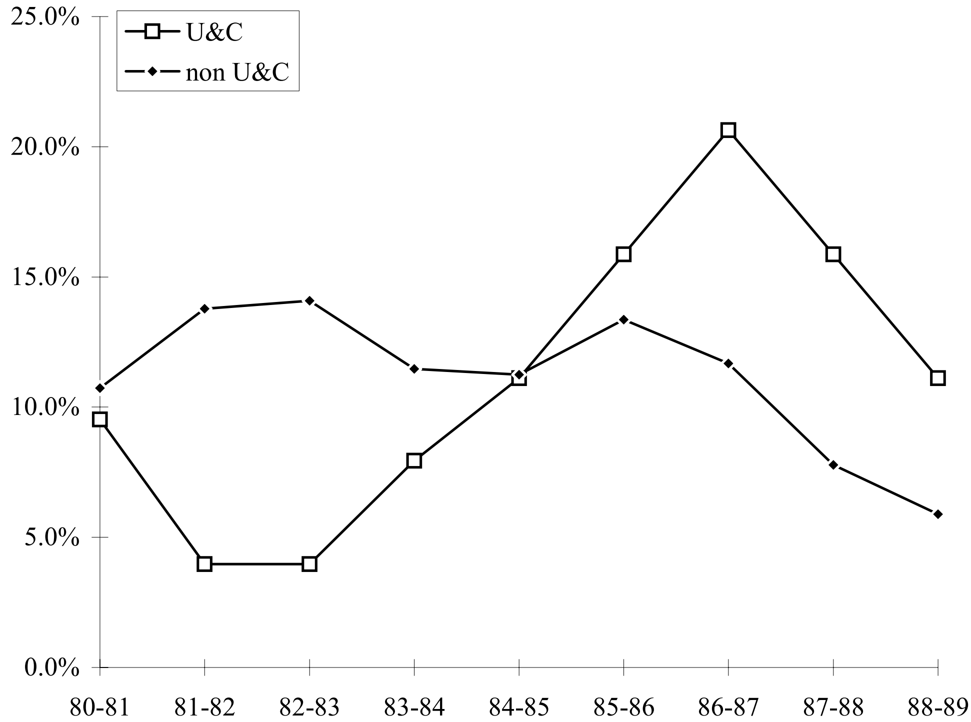

Figure 4-4 Distribution of inventor-authored publications over a 10 years period, university/company co-operations vs. others

Although the total number of publications involved is slightly lower than in the CICA analysis, the distribution is remarkably similar. From about 1984, there is a sharp activity increase of university-company co-operation (again, as far as reflected by publications covered by the SCI), culminating around the years of patent application, 1986/1987. Afterwards, the U&C activity decreases to an average number of papers per year. A notable dip is found in 1980/81, long before the increase, and we are still uncertain about the cause. The trend of the other publications (i.e., with only a university, or only a company as an address, or any other address) fluctuates, like the overall trend, around the average, again with a small decrease in the two most recent years.

We conclude that we found a second bibliometric indicator to define 'patent-related publications'. We showed that this second bibliometric indicator also illustrates an increase of R&D activities in the period around patent application, in the same way as the CICA indicator.

4.3.4.2 Patent application vs. publishing

In addition to these results, we focus on a delicate issue concerning publishing inventors. It is clear that a new invention must be original in order to be patented. It is therefore not surprising that a patent application can only be accepted if nothing has been published about the invention up to the day of application. Not by others, nor by the inventors themselves. An actual publication about the work described in a patent, and, thus, with the same innovation disclosures, can therefore only be published after the application date of the patent involved.

Taking this consideration into account, one should conclude that the publications responsible for the increase of co-activity of inventors ('CICA=1' publications) and the increase of co-operation between universities and companies (U&C publications) around the date of patent application, do not include the papers which do actually disclose the invention. In that case, a patent application would never be granted for lack of novelty.

It illustrates, however, once more that patents applications and scientific papers should be considered as two different components of the same (in broader terms) R&D output. In our sample, these two components seem to be complementary.

4.4 Conclusions

The number of non-patent literature (NPL) references in laser medicine patents correlates significantly with the degree of 'appliedness' of the inventor-authored publications in the period around the patent priority year. Furthermore, we found a correlation, although not strong, between the number of NPL references in the patents and the number of references in those inventor-authored publications that are most related to the patent work.

What do these two findings mean? We think that they do *not* prove that the number of NPL references in patents are a measure, for an *individual* patent, of the 'science intensity' as such. But, rather, a technological field or specialty is science-intensive as such, or, in other words, science intensity is an *intrinsic property* of certain (sub-) fields of technology (Grupp & Schmoch [5, pp.90-98]). In our opinion, the first finding shows that there are patents in a specific field of technology (in this case: laser medicine) that are typically *technological* in nature (e.g., new instrumental developments). For the R&D work involved, both the 'science side' (publications) as well as the 'technology' side (patents) thus have a more applied character, resulting in the use of typical applied journals, and less (or none) NPL references in patents. The conclusion could be that *if* patent work is more related to applied research, the necessity of the patent-examiners to explicitly list NPL references in the patent decreases. Thus, inventions with technology orientation can well be science-intensive.

The second finding is quite interesting in the light of the above explanation. The scientific work related to the more typically technological patents (having less or none NPL references) also seems to have less references in the publications. This, however, is in fact the other side of the same coin: Narin [7] found that the more a publication is applied in nature, the less references are given (in the SCI data).

In conclusion, we found that less or no NPL references in patents is not necessarily an indicator of a lesser science intensity of the individual patents (since, for example, the number of inventor-authored publications and the received citations *do not* discriminate between patents with less or more NPL references!), but an indicator of the more technological nature of individual patents. Thus, patent documents with no or only one NPL reference cannot be regarded as significantly less 'science-intensive' as such (but probably: less *basic-research*-intensive) than those with many NPL references.

The findings based on expert opinions on the individual patent documents, indicate that the entire R&D field of laser medicine depends on scientific progress. Those patents containing more NPL references are often more complex, i.e., include more claims, but are not necessarily more science intensive. They may, however, be more basic-research intensive. This meshes with the expert opinion that a complex set of legal claims corresponds to a more general description of possible commercial applications.

If we drop the original distinction of three NPL-based patent subsets (and, with that, the relation with NPL-based indicators of science intensity) and focus on the total scientific oeuvre of all patent inventors, we find further important characteristics.

First, there is a significant increase of inventor co-authorship in the period before the patent priority year. Second, the data show a significant increase of university-company collaboration (as far as reflected by our bibliometric method) again in the period before the patent priority year. It is plausible, however, that both phenomena are related: if part of the inventors' team is affiliated to a company, then an increasing university-company collaboration implies a similar trend in inventor co-authorship.

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5 Bibliometric Cartography of Scientific and Technological Developments of an R&D field: The Case of Optomechatronics*

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Bibliometric Cartography of Scientific and Technological Developments of an R&D field: The Case of Optomechatronics

Abstract

This paper presents the results of an exploration of bibliometric mapping as an analytic tool to study the important aspects of the relation between science and technology, in particular the 'science base' of technology. We discuss a bibliometric (in particular a publication- and patent-based) approach to develop a cartography of science and technology, i.e., the construction of geometrically organized maps in order to visualize the changing internal structure of science and technology. These maps are based on co-occurrences of publication and patent keywords.

We focus on a specific R&D field: optomechatronics. This field is characterized by a strong knowledge transfer between science and technology. We constructed maps for both the science as well as the technology 'side'. Comparison of these two allows the exploration of existing or possible interaction of scientific and technological developments. We identified related subfields (co-word clusters) in the maps of both 'sides' in order to illustrate the interaction between science and technology. Subsequently, we extended the information given by the maps with information on the role and position of a number of countries in the different subfields of optomechatronics, both at the science side as well as at the technology side. This is done by identification of actors in the subfields represented by word clusters in the maps.

Cartography of science and technology allows the observation of the structure (and its changes) of scientific and technology fields. Moreover, it illustrates both existing as well as possible links between science and technology. It therefore presents a powerful tool for science, technology and R&D policy.

5.1 Introduction

5.1.1 Science base of technology

Bibliometric studies on the scientific base of technological development have up till now always been based on direct relations between science (represented by scientific articles) and technology (represented by patents). These direct relations were found in patent references to scientific articles and in inventors publishing scientific papers.

Studies based on the Non Patent Literature (NPL) references in patents (Narin & *Olivastro*, 1988; *Noyons* et al., 1991; *Grupp* and *Schmoch*, 1992), pointed out that these references give an indication of the science relatedness of a technology field. In general, they observe a higher number of NPL references in patents when a technology field is more science-related. It should be noted, however, that this science-relatedness is a clear and direct one. The patents refer directly and unambiguously to the science literature. Furthermore, we know that when a patent document contains a reference to a scientific publication, the knowledge transfer from science to technology has actually taken place (directly via the inventor or applicant or via the patent examiner). This is even better illustrated when an inventor has also published scientific papers (*Rabeharisoa*, 1992; *Korevaar* and *Van Raan*, 1992; *Noyons* et al., 1994). In such cases scientific knowledge appears to have been used directly for technological application.

Methods based on such direct relations, obviously, do not deal with situations in which the relations between science and technology are not so direct and unambiguous. Scientific papers are not always referred to in patents when used for technological application. Sometimes because inventor nor examiner is aware of the scientific work, sometimes because *similar* work has been referred to, and sometimes because a scientific publication is not used directly, but rather via another scientific publication (e.g., follow-up, review). For the inventor-author relation, it takes a closely science-related technology field to find authors being inventors or the other way around. Such direct relations are not to be expected in every technology field.

In *Noyons* et al. (1994), we also observed that the lack of NPL references does not necessarily mean that there is no science link at all. In such cases, we are not able to investigate the science base of technology by using NPL references only. And, in a technological field with no strong interaction between science and technology, we are not able to do so by using the inventor-authored scientific publications.

By using a cartographic approach, we try to deal with short-comings of bibliometric data in such cases, by investigating the science link between science and technology on the basis of a cognitive overlap. We try to identify similar subfields (co-word clusters) in the maps on both 'sides', constructed on the basis of the same definition. Thus we do not identify links between science and technology which are actually present, but rather links which could be there, or even *should be* there. Eventually this approach may prove to be a useful tool for companies to identify research activity for (further) development of products and for research institutes and universities to identify possible application of knowledge.

5.1.2 Basic principles of bibliometric cartography

Science and technology constitute complex, heterogeneous knowledge domains of different fields of activity, characterized by many interrelated aspects. Systematic investigation of this network of interrelations, and with that, the *structure* of science and technology and their *interface*, is a crucial element in the study of R&D. Nowadays, there is an enormous and ever increasing amount of information on science and technology. It is a challenge to develop techniques for extracting well-structured patterns of information from such a rather 'amorphous' mass of data. These patterns may reveal underlying and until now hidden features reflecting cognitive relations. An exciting approach is the development of *bibliometric maps*. There are several important advantages of using such cartographic representations. Visualization of complex masses of data offers a more complete overview in less time. In addition, visual information is more easily remembered. Another important point is the reduction of information. Bibliometric mapping allows the filtering of significant features. Time-series of maps may offer a *dynamic view* of the structural developments of science and technology. For instance, identification of important changes over time in the development of particular fields, such as synthesis of fragmentation of these fields, the increasing importance of specific instrumentation, emerging new activities, or shifts in R&D emphasis of countries and companies. Moreover, comparison of the 'knowledge structure' at the 'science side' of an R&D field with that at the 'technological side' may reveal important information about the 'science base' of technology. The empirical exploration of this hypothesis is the central aim of this study.

As bibliometric maps are based on data in publications and patents, this cartographic approach is independent of single, individual opinions. This is particularly advantageous in the case of broad and heterogeneous fields. This does not mean that bibliometric maps can *replace* opinions of experts. Design and use of bibliometric maps will be optimal in interaction with experts in the field, preferably the 'users' directly involved in the application of the maps.

In bibliometric analysis we may distinguish between *one-dimensional* and *two-dimensional* techniques. One-dimensional techniques are based on *direct* counts (occurrences) of specific bibliographic items (e.g., publications and patents), or particular data-elements in these items, such as citations, keywords, or addresses. We call these techniques 'one-dimensional' as they are in principle represented by *lists* of numbers. Two-dimensional techniques allow the representation of *relational features*. They are based on *co-occurrences* of specific data-elements, such as the number of times keywords or citations are mentioned together in publications or patents in a particular field.

The advantage of the bibliometric method is the possibility to map relationships between *any* co-occurrence of bibliometric data-elements. Thus, a structure of related keywords, or of related references, or a structure generated by combinations of key-words, references and/or classification codes can be made. Each possibility refers to another aspect of the science and technology system and can be applied to different levels of aggregation (varying from R&D groups to entire companies, business sectors, or countries, or even entire fields of science and technology). For a recent review on bibliometric mapping based on different co-occurrence techniques, we refer to *Tijssen* and *Van Raan* (1994).

In this paper we focus on bibliometric mapping based on *word co-occurrences*. Word co-occurrences in a set of publications or patents reflect the network of conceptual relations from the viewpoint of scientists and engineers active in the field concerned. These 'co-word' frequencies are used to construct a co-word map which represents the major themes in a field and their interrelations (*Callon* et al., 1983, 1986). The main advantage of co-word analysis is given by the nature of words: words are the foremost carrier of scientific and technological concepts, their use is unavoidable and they cover an unlimited intellectual domain. An important semantic problem is that the meaning of words is often context-dependent. However, the co-word approach is in fact based on 'words-in-context' (i.e., words placed in relation to relevant other words). Therefore, co-word maps can be regarded as (of course, as yet rather 'primitive') semantic maps.

For a detailed discussion of the main methodological aspects of publication-based science maps and patent-based technology maps, we refer to our recent publications (*Van Raan* and *Tijssen*, 1990; *Engelsman* and *Van Raan*, 1991, 1994; *Peters* and *Van Raan*, 1993). The basic principle is that for each of the keywords the co-occurrence with any other keyword in a set of publications or patents is analyzed, i.e., we count the number of publications or patents having any possible pair of keywords. With matrix-algebra techniques this co-word matrix is displayed in two-dimensional space, and the keywords are positioned in the map according to their mutual relations. This means that the relative distances between research topics indicated by keywords in the map reflect their cognitive relationships from the statistics of the underlying data in publications or patents. The above sketched process of publication- and patent-data collection, composition of co-word matrices, and construction of maps, is highly automated. This enables us to make science and technology maps in a reasonably economic way. A detailed discussion of the co-word methods and techniques to compare scientific and technological developments of specific R&D fields is given in a paper on a parallel study (catalysis and environmental chemistry) by *Korevaar* and *Van Raan* (1992). In this paper, we focus on the bibliometric mapping of the science and technology 'side' of an R&D field, which is considered to be one of the most important new 'generic technologies': optomechatronics.

5.2 Maps of optomechatronics based on expert field definitions

Optomechatronics is an R&D field in which optical, mechanical and electronic technology is combined. It is a field of strongly growing technological importance.

We applied a definition of (opto-) mechatronics as given by a group of European Community experts, the IRDAC (Industrial Research & Development Advisory Committee). The definition is used both to identify relevant publications on the science side and to select relevant patents on the technology side. In earlier work

(*Engelsman* and *Van Raan*, 1991 and 1994; *Noyons* et al., 1991) we used definitions based on specific keywords and patent classification codes.

5.2.1 Method and data

We investigated the 'science side' and 'technology side' of optomechatronics and, more specifically, science as a basis for technology. Particularly, we expect to find in our maps subfields on the science side related to (subfields on) the technology side, and the other way round. Such 'communicating' subfields should be recognized both by specific words in the clusters representing a subfield, and by the (type of) actors found in the clusters.

In the above mentioned IRDAC definition, 6 subfields are distinguished:

1. Mechatronics Systems Design Analysis and Modeling;
2. Sensors;
3. Actuators;
4. Advanced Control Techniques;
5. Interconnection techniques and Standardization Needs;
6. Precision Mechanism and Mechanical Devices.

This IRDAC definition of the field was translated into search terms for both INSPEC and WPIL. Thus, the selection of articles and patents from databases representing both sides (INSPEC for the science side, and WPIL for the technology side) was performed in a comparable way. For each of the two databases we took the most recent 'publication' year, taking into account the entry delay. In INSPEC, we selected articles with publication year 1991, and in WPIL patents with priority year 1989. We stress that the use of the whole WPIL database, yields a severe bias towards Japanese patents. In *Engelsman* & *Van Raan* (1991, 1994) it is argued that Japanese domestic patenting traditions strongly influence the numbers of patents. A possibility to make a more 'realistic' picture of technological activities is the restriction of patent analyses to the US and the European Patent Offices. Important Japanese inventions will be included as most of these inventions lead to patent applications in the US and in Europe. However, exclusion of Japanese domestic patents might push recent developments in Japanese technology into the background. Thus, selection of patents depends upon the type of analysis.

From the set of publications in INSPEC a list of the most frequent controlled terms (CT) and uncontrolled terms (UT) was generated. CT's tend to cover publications with subjects already established within the field, whereas UT's are more 'author related' and possibly cover more new developments (*Van Raan* and *Van der Velde*, 1994). Therefore, we used both CT's (90 most frequent) and UT's (10 most frequent, not already being CT's) as input for the science map. From the WPIL patent set a frequency list of indexed words (IWs) was generated, from which we used the top-100 as input for the technology map.

Both the science as well as the technology map were constructed with help of co-occurrences. We used the above matrices (100 * 100) for multidimensional scaling (MDS) in which word distances on the map are based on the cosine index. For more details of the mapping techniques we refer to *Engelsman* and *Van Raan* (1991, 1994) and to *Noyons* et al. (1991).

Furthermore, the following additional information was included on the maps (a detailed discussion is given in the paper on a parallel study by *Korevaar* and *Van Raan* (1992).

(1) on the basis of distances between words calculated with the cosine index, single-linkage clusters were drawn in the map. If two words have a cosine index above a certain threshold, they are captured in one and the same cluster. The threshold is set to a value which yields a maximum of clusters (of two or more words);

(2) on the basis of 'individual' relations ('pair linkages') between words in the map, in terms of the inclusion index, lines were drawn in the map illustrating these relations as far as the two words are not already captured in one and the same cluster. This is particularly important for words in different clusters, but with a strong 'individual relation'.

For the identified clusters in the map of the science side we applied an 'actor analysis' (see Section 3.2.3). For each major cluster in this map the addresses of the authors of the publications concerned have been analyzed. In particular, we characterized the affiliations by *institute type* (e.g., university institute, company, governmental organization). For this purpose, the list of institutional addresses was matched with an in-house-database with unified and 'cleaned' addresses derived from a large set of scientific publications from most western countries (*De Bruin* and *Moed*, 1990). This 'address master file' also contains information about the *institute type* of most of the covered addresses. In order to match the list of institutional addresses in optomechatronics with the master file, a country name in the address of a publication is essential. As we analyzed publication data with help of INSPEC, the availability of the country name was not a big problem, only in a few cases the country name was not available. But it was much more problematic to match the institute names (as given by INSPEC) with the master file. Eventually, we were able to label 96% of addresses with an institute type. The remaining 4% was either not found in the master file, or not yet labeled in the master file with an institute type.

5.2.2 Results

5.2.2.1 Two maps based on one definition

In the map of the science side (see Figure 1), we observe three main parts. A large network of subclusters containing terms like 'design', 'expert systems', 'adaptive control', 'optimal control', 'stability' and 'control system synthesis'. A second part covers a subfield of 'semiconductors', 'sensors' and 'silicon'. Furthermore, there is a mechanical cluster of 'motors' and 'drives' around 'digital control'. For reasons of clarity we identified, within the large network of (sub) clusters, 5 meaningful clusters for labeling. The resulting breakdown of the major cluster is as follows:

I Design, expert systems, knowledge representation, etc.;

II Stability, control system synthesis, etc.;

III Optimal control, dynamic programming, etc.;

IV Adaptive control, self adjusting systems, etc.;

V Robots and position control;

Next, we have the earlier mentioned two other clusters which appear to be rather 'autonomous':

VI Semiconductor, silicon and sensors, etc. ;

VII A mechanical cluster around digital control.

Cluster I covers research on the design of expert systems including CAD/CAM and manufacturing systems. A major concern of this research is the design of controlling systems. In the surrounding clusters (II, III, IV and V) several closely-related topics are covered, III taking a central position. The latter obviously has a connecting function between all 'control' clusters. Cluster VI covers research of integrated circuit (IC-) technology, sensors and semiconductors. Cluster VII includes research on 'machine control' and, via 'digital control' also 'microcomputer applications' research.

As far as the technological side of the field concerns (Figure 2), we observe a much less complex structure. There are two major clusters to which most other activities are adjacent. First, the *actuator/control techniques* (ACTUATE/CONTROL) cluster, on the right-hand side, is not very large in terms of the applied single linkage clustering, but it attracts all peripheral words and clusters, if we apply inclusion linkage with the word 'control'.

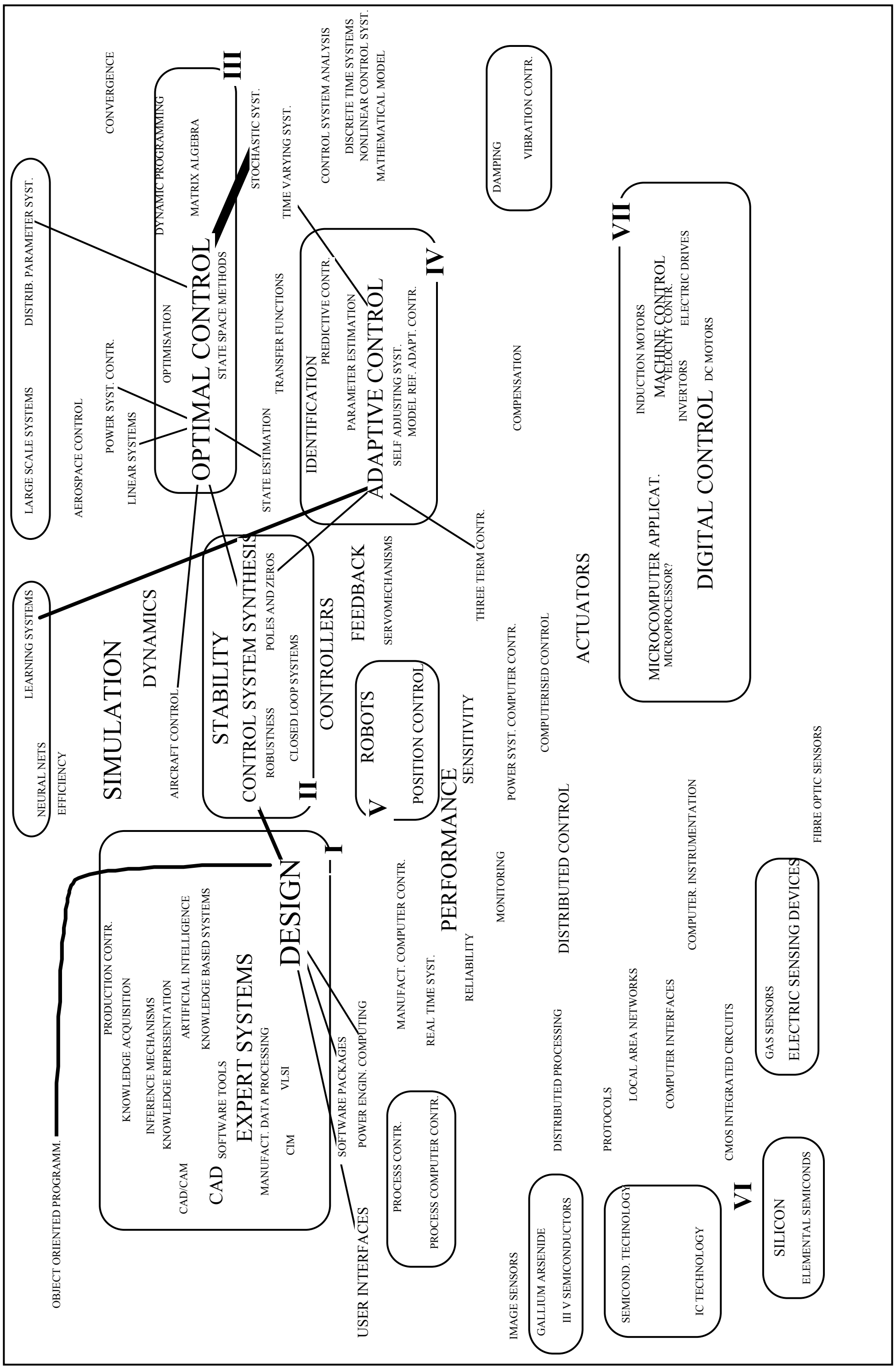

Figure 5-1 Map of the 'science side' of optomechatronics (1991)

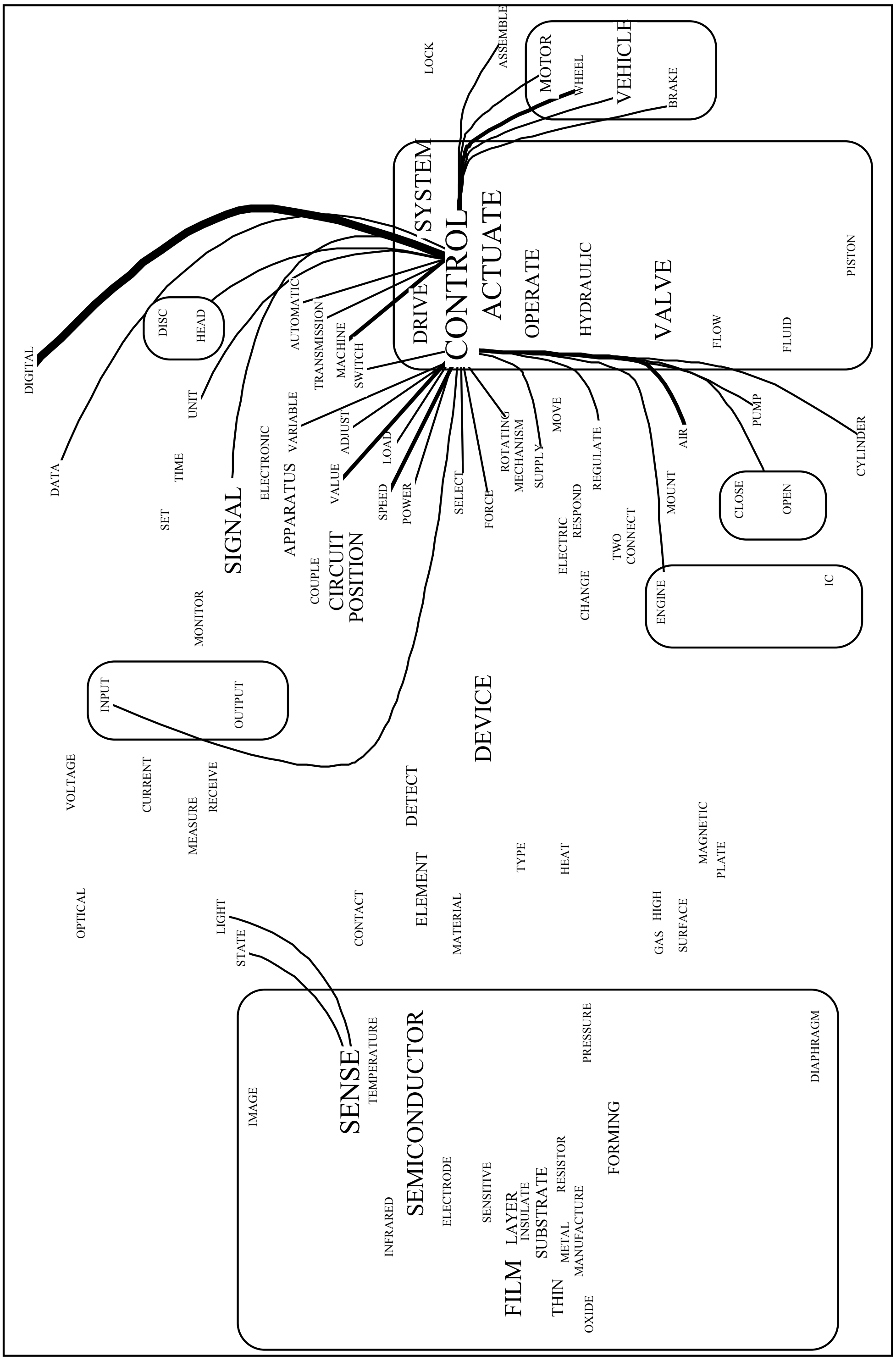

Figure 5-2 Map of the 'technology side' of optomechatronics (priority year = 1989)

Second, on the left-hand side, we observe the larger sensor (SENSE) cluster. In fact, this cluster looks larger as it contains more words, but actually it covers less publications than the *actuator/control techniques* cluster. The *sensor* cluster containing words like 'semiconductor', 'gas', and 'sensing', corresponds to cluster VI of the science map. The *actuator/control techniques* cluster corresponds to cluster VII of the science map. The other clusters of the science map are not directly related to clusters in the technology map. In other words, only very few terms from other clusters in the science map are found again in the technology map. In these scientific clusters (I-V), however, a lot of research is involved that has resulted in computer software. Therefore, as software cannot be patented as such, it is not expected to appear in the technology map based on patent applications.

In a recent report (*Noyons* and *Van Raan* 1993) we extensively compare our results as presented in this paper (and based on the IRDAC definition) with our earlier maps (*Engelsman* and *Van Raan* 1991, 1994; *Noyons* et al. 1991). In main lines, we reach the following conclusions. Optomechatronics, being an important, strongly developing R&D field in which the integration of several already highly developed fields take place, can be defined in different ways. Each definition emphasizes particular aspects of the field. We also observe that different definitions cover different links in the chain from scientific research to technological application. Our science map (Figure 1) based on the IRDAC definition of (opto-) mechatronics appears to cover scientific research in the most basic sense (i.e., most basic for the field). Here the different kinds of control systems are included. Moreover, there is a specific cluster of mechanical control applications, and a cluster of sensors, semiconductors and integrated circuit technology. These clusters are the most prominent composing parts of the field. The typical optical R&D takes its position more or less at the center of the map. *Busch-Vishniac* (1991) discusses the techniques used for micro-automation, which is positioned at this point of the map. These techniques supported by sensor and actuator technology is represented by words like: controllers, feedback, servomechanisms, position control, manufacturing, actuators, sensors and fibre optics.

In our technology map (Figure 2) we observe applications of sensors and semiconductors on the one hand, and mechanical control techniques on the other. The conclusion that 'expert systems' and other aspects of control techniques as represented in the science map are not found again in the patent-based technology map, is probably due to the fact that the application of this subfield concerns mostly software, which is not patentable. Furthermore, the technology map lags somewhat behind in time as compared to the science map. Our technology map, therefore, represents particularly the science and technology interface (not surprisingly, the contents of our earlier science and technology 'interface map' (see Figure 11 in *Engelsman* and *Van Raan* 1994) is almost fully covered in this map). The specific micro- (and macro-) automation techniques are positioned in between the two major clusters in our technology map. Relevant words are: sense, semiconductor, layer, plate, magnetic, surface, optical, control actuate, position, circuit, speed and others (see Busch-Vishniac, 1991). We also find the inclusion of optical techniques, which is hardly covered by the earlier maps.

5.2.2.2 The role of actors

For the clusters in the science maps based on the IRDAC definition (Figure 1 and Figure 2), we applied an actor analysis. We identified the institutes responsible for the publications as represented by the word clusters in the map.

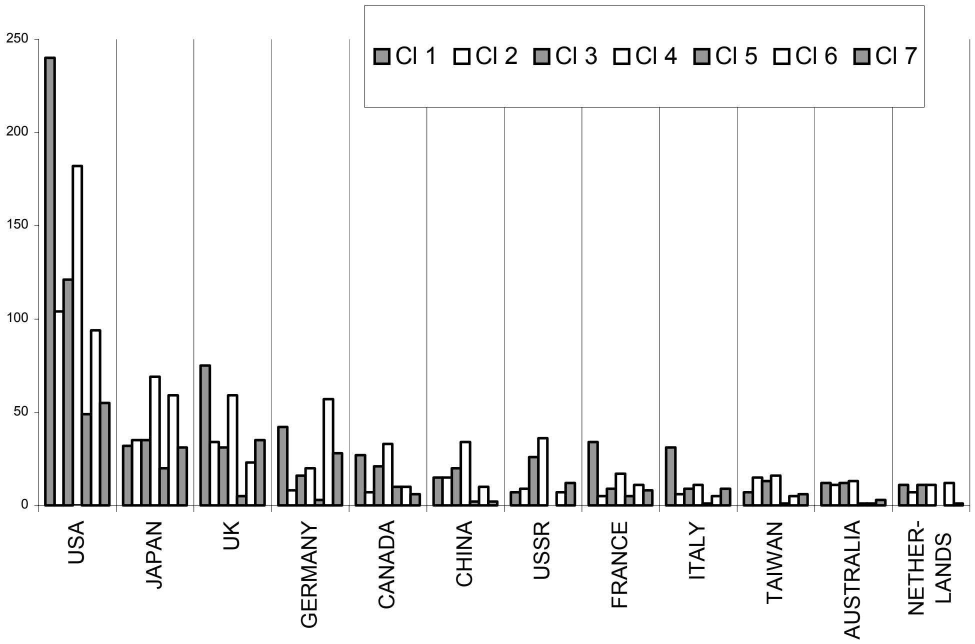

Figure 5-3 Number of publications per country per cluster, 'science side' of optomechatronics

The seven clusters of the science map are separately analyzed with help of the INSPEC database, by combining all possible word co-occurrences within a cluster (e.g., for cluster X with words A,B and C we use the combination [A*B] + [A*C] + [B*C]). For the resulting set of publications we identified the institutes involved (i.e., affiliations of authors). For each cluster a frequency list of active institutes was generated. This list was touched up with additional information if country or city names were missed in the database. Thus we were able to determine the most active countries per cluster. In Figure 3, the results are plotted for the 13 most active countries.

Not very surprisingly, the USA is the most active country in all 7 clusters. Only in cluster VI and VII they are more or less approximated by Japan and Germany, in cluster VII also by the UK. Another remarkable finding is that Japan appears to have such a relatively small activity in cluster I, which is the main subfield for almost all other countries. Apparently, Japan focuses more on cluster VI, and on cluster IV which, however, is also important for most of the other countries. The Netherlands also has its main focus of activity on cluster VI, has no 'measurable' activity in cluster V, and hardly any in cluster VII.

The institutes active in each cluster have been characterized by type. A large in-house database (with affiliations of scientific authors in a unified address structure) was used for this purpose. This database includes, among other, information about the *type* of the affiliations. In this 'CWTS address master file', seven types of institutes are distinguished:

1. Universities (U)
2. Colleges etc. (E)
3. Companies (C)
4. Governmental institutes (G)
5. Research institutes (R)
6. Hospitals (H)
7. International Institutes (I)

As some of the addresses in the master file are not yet labeled with an affiliation type, and some addresses were not found in the master file, we introduced an eighth type (X) attached to those not identified. Moreover, as we found it difficult in many cases to determine U or E, these two institute types are joined together in our analysis.

By comparing the number of institute types in each cluster, we were able to characterize the kind of research in a subfield (cluster), as represented by its 'institute type'. The results are shown in Figure 4.

In the above we are dealing with the science side of optomechatronics. Therefore, it is not surprising that most research in all clusters is done at universities and in colleges. In cluster VI and cluster VII, however, significantly more companies are active than in any other. In clusters I to V, the number of companies involved hardly exceeds the share of research institutes.

Apparently, industry takes higher interest in the research of cluster VI and VII. This will be further supported by our findings for the technological side of the field (see next section).

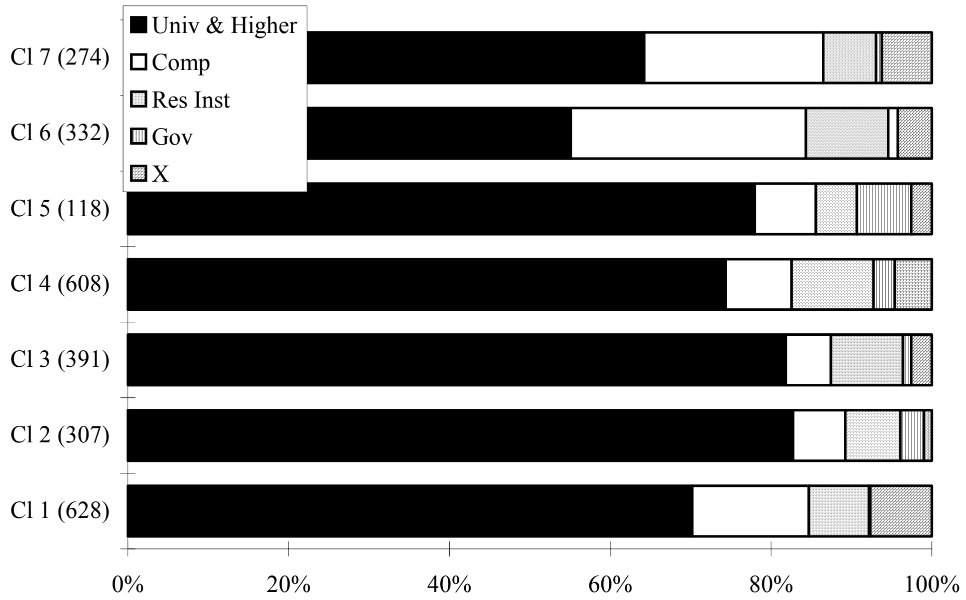

Figure 5-4 Percentage of institute types per cluster, 'science side' of optomechatronics

Subsequently, a profile of 13 most active countries with respect to number of institute types is made (see Figure 5). In most countries, universities and colleges have the largest share. In Taiwan even 100% is academic. Only in the USSR, research institutes (in particular the *Ukrainian Academy of Science* (ACAD SCI UKSSR) in Kiev, and The *Institute of Control Science* (INST CONTROL SCI) in Moscow) outnumber universities. This, however is characteristic for all Soviet scientific activities (*Piskunov* & *Saltykov*, 1992). The number of not identified institutes is never more than 5% except for France. More than 25 % of the addresses from this country could not be labeled with a type. Not surprisingly, in Japan the share of companies involved is larger than in any other country, although they do not exceed universities and colleges. The most active companies from Japan are *Fujitsu LTD*, *Hitachi LTD*, and several departments of *Nippon TT*. The UK is traditionally more academic-oriented.

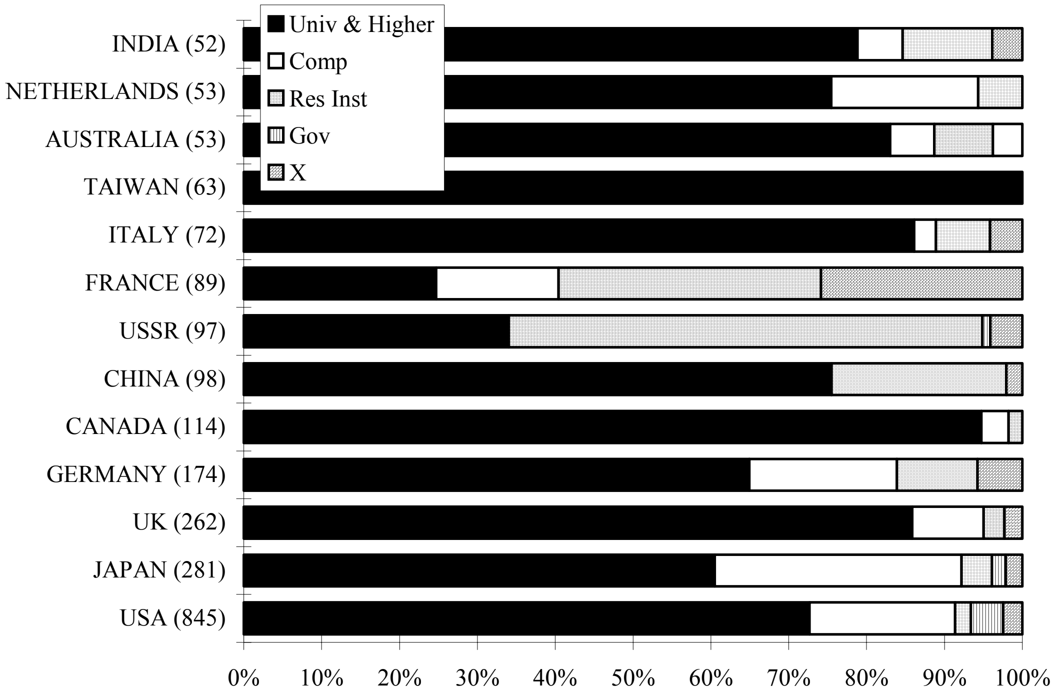

Figure 5-5 Percentage of institute types for 13 most active countries, 'science side'

The large amount of active research institutes in France is due to the fact that CNRS institutes are identified as such. It may, however, well be argued that most of the publications from these institutes are in fact academic.

In the Netherlands no deviant pattern is observed, with universities being the most active institutes (particularly the *University of Technology at Delft* (TECH UNIV DELFT), followed by companies (*Philips*) and research institutes.

For the technology side, ongoing work is devoted to identify actors in terms of inventors as well as applicants.

5.3 General conclusions and discussion: overview of possibilities and limitations

Bibliometric cartography based on publications and patents is a powerful tool to analyze the structure of science and technology. Mapping of R&D fields offers the possibility to visualize the internal structure of these fields. In fact, a geometrical structure in abstract space is constructed, reflecting the cognitive relations covered by the statistics of the data in publications and patents. This reveals centers of invention activities which can be analyzed further in terms of countries, companies, R&D laboratories involved, etceteras.

Time series of maps allow an impression of important temporal changes. A more detailed discussion is given by *Noyons* & *Van Raan* (1993). We found that recent developments are based on the main lines of preceding periods. This means that on the basis of the contours and patterns visible in the most recent maps, medium-long term predictions about future developments can be made.

In this paper, we have presented the results of an analytical, 'cartographic' study of science as a base of technology. As a starting point we used the bibliometric maps representing the field of optomechatronics. For the science map of the field we performed an *actor analysis* by identifying the countries and institutes or companies involved in the publications representing clusters (subfields) in the map. We found that this bibliometric actor analysis is a useful tool to determine the relative activity of countries and/or companies, in comparison to the activity in the same cluster by other countries and companies, or to the activity in other clusters.

In the maps we implemented a method to relate the science and technology side. The selection of field-specific patents and publications was based on the same definition (IRDAC definition). The resulting maps (Figs 1 and 2) show, in main lines, the same cluster structure. Though there is no *direct* connection between the related clusters in the science map on the one hand and the technology map on the other, we conclude that the research activities represented by the corresponding clusters in the science map can (or should) be considered as a science base for the two technology clusters. Thus, the institutes active in these science (base) clusters perform research which is, or could be, important for applications represented by the patents in the corresponding technology clusters.

We found that the used databases (INSPEC and WPIL) are quite appropriate for our purposes, but that there still are several shortcomings. One basic problem is related to the use of any patent database. In the most recent science map we identified about five clusters on several aspects of *control*. These clusters were not identified in the technology map because most of these techniques involve software which is not patentable. By using a patent database, we miss such technological applications. In view of the problematical jurisdiction around patenting software, we do not expect much progress on this point in the near future. Given our experiences with maps based on data from COMPENDEX (*Van Raan* and *Van der Velde*, 1994), we expect that such a typical engineering database may provide a useful combination of (applied) scientific, technological and software developments.

As far as our 'actor analysis' concerns, we conclude that on the 'science side' of optomechatronics the USA , Japan, the UK and Germany are the leading countries. In Japan a significantly large share of research is done in companies. Furthermore, it is striking to see that Taiwan and China take such high interest in the optomechatronics research. In these two countries almost all work is done in universities and research institutes (of course, as far as our bibliometric approach can reveal). For the Netherlands we observed a high interest for Cluster VI (*sensors and semiconductor technology*). The emphasis on research in this subfield is also found in Germany and Japan. These two countries are also interested in cluster VII (*mechanical and digital control*), which is not the case for the Netherlands. Most of the other countries are more active in cluster I-V (research on several *control techniques*).

A possible enrichment of the cartographic analyses is an investigation of the direct links between science and technology in terms of patent citations to non-patent literature. If such relations are actually present, it would be interesting to find out if they refer to the links found in this study. In future research we will elaborate on this.

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6 Monitoring Scientific Developments from a Dynamic Perspective: Self-Organized Structuring to Map Neural Network Research[*]

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Monitoring Scientific Developments from a Dynamic Perspective: Self-Organized Structuring to Map Neural Network Research

Abstract

With the help of bibliometric mapping techniques, we have developed a methodology of "self-organized" structuring of scientific fields. This methodology is applied to the field of neural network research.

We propose a field-definition based on the present situation. This is done by letting the data themselves generate a structure, and, with that, define the subdivision of the research field into meaningful subfields. In order to study the evolution over time, the above "self-organized" definition of the present structure is taken as a framework for the past structure. We explore this evolution by monitoring the interrelations between subfields and by zooming into the internal structure of each subfield.

The overall ("coarse") structure and the detailed subfield maps ("fine structure") are used for monitoring the dynamical features of the entire research field. Furthermore, by determining the positions of the main actors on the map, these structures can also be used to assess the activities of these main actors (universities, firms, countries, etc.).

Finally, we "reverse" our approach by analyzing the developments based on a structure generated in the past. Comparison of the "real present" and the "present constructed from the past" may provide new insight into successful as well as unsuccessful patterns, and "trajectories" of developments. Thus, we explore the potential of our method to put the observed 'actual' developments into a possible future perspective.

6.1 Introduction: analysis of the structure of science and technology

An important question in the analysis of scientific and technological developments is the following: how can one define and delineate a particular field of science and technology? Nowadays, there is a large universe of bibliographic databases and other document-related data (Van Raan, 1996). The Internet makes this universe ever-expanding. Thus, the first problem is selection: the choice of an appropriate data source. After this *higher aggregation level* choice has been made, the problem of selecting relevant data within the chosen source(s) arises [5]. Papers (or patents or documents in general) representing a science (or technology) field, are usually selected on the basis of key-terms, classification codes, journal names, authors names, or author affiliation addresses. Often, an iterative process is applied: documents selected, for instance, by key-terms yield in turn other (probably less central) terms,

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[5] An extensive study on this matter is performed by McCain & Whitney (1994)

which are then used to extend the selection of documents in order to cover the field more widely.

Then, after the last selection step, the whole set of documents has to be ‘structured’ in order to make the data accessible and manageable. This structure should be such that the component parts provide a meaningful division of the field, representing research subfields and application areas. This is particularly important for evaluative purposes, for instance to assess the role and position of actors (countries, universities, companies) in the field (see, for instance, Grupp, Schmoch & Koschatsky. 1998).

If one starts with a document as a unit of information, there are several ways one can obtain a *structure of science*. They are all related and are based on specific characteristics of the document. These characteristics are, for instance, the journal in which the document is published, the references given in the document, and the document’s keywords or classification codes.

Structures always arise because the composing elements have particular linkages, indicating degrees of relatedness. Here, we have a similar principle: Documents appear in the same journal, or they have a smaller or larger number of references, keywords, or classification codes in common. Typical bibliometric techniques such as co-citation and co-word analysis are based on this principle (Callon, Courtial, Turner & Bauin 1983; Callon, Courtial, & Turner 1991; Healey, Rothman & Hoch, 1986; and Leydesdorff & van der Schaar, 1987). For more details of these techniques, we refer to appropriate reviews (e.g. Tijssen & Van Raan 1994).

In this article we try to go a step further. By applying these relatively familiar bibliometric co-occurrence techniques as instruments, how can we develop an effective methodology of self-organized structuring of science and technology? So our claim is not so much to be original by reinventing good old techniques, but rather to redesign and improve them as useful instruments for a new conceptual framework and to shape a new methodology.

Let us give some examples of how structures based on scientific or technological documents can be obtained. For these examples we focus on scientific publications.

A first approach is based on *journals* as a structural unit. Let us consider, for example, the application by ISI (Institute for Scientific Information) of *journal categories* - a classification in terms of the journal in which a publication appeared. A specific group of journals (a journal category) is considered to represent a scientific (sub)field. The entire set of categories is then supposed to cover the worldwide scientific output in all disciplines, at least to a first, but reasonably good, approximation [6].

[6] Katz and Hicks (1995) and Katz et al. (1995) present a multi-level scheme for evaluative purposes, which is also applicable to study interdisciplinary developments.

Another approach is based on *individual documents* as the structural unit, with each publication in a given scientific database being given to one (or more) (sub)fields: The classification being based on appropriate codes or keywords for each individual publication.

It is clear that for any specific publication only *one* journal - by definition - can be assigned, whereas the same publication can be characterized by a set of classification codes or keywords. Categorization of publications at a journal level often provides a first and useful structure. It is, however, rather coarse as this categorization is at a higher aggregation level than the individual publication. In particular, one has to cope with the severe problem of the multidisciplinary or multi-field character of many journals. We often find that although the journal used is multi-disciplinary (or at least covers a range of disciplines), the publication itself has a narrower scope. For instance, an astrophysics article in *Nature*.

Characterization of a publication solely on the basis of its journal would therefore result in this article being incorrectly assigned to more than one (sub)field. In the opposite case, where a publication has a broader scope than the journal, information may be lost as the publication may be assigned to one field only, namely the field in which the journal is categorized.

6.2 Shaping a methodology of self-organized cognitive structuring

The above discussion shows the disadvantages of structuring science by assigning publications to fields on the basis of journals. The use of keywords and classifications codes for individual publications, regardless of journal, would solve most of the above problems. It is clearly a much more refined method of assignment. But it still depends on fixed classification and thesaurus systems: The assignment of specific keywords and classification codes (descriptive terms) obeys rather strict rules, based on the views of the database producer.

Thus, an important drawback is the rigidity. The definition of (sub)disciplines or fields normally refers to notions about the cognitive structure of science in the past, and does not always take into account present (let alone probable future) developments. Note however, that almost ironically for evaluative studies this rigidity appears to be more or less required. For instance, in order to analyze the role of actors in a longer period of time, we somehow need to keep the definition of the field fixed, and thus a specific part of the structure of science unchanged during that period (Noyons et al. 1995; Noyons & van Raan, 1995). Otherwise, important analytical methods such as the exploration of trends cannot be applied in a reliable way.

As mentioned above, database-related definitions of research fields rest on accepted notions about the scientific structure. In other words, it is based on the past. We, however, would like to take the present, as far as possible, as the starting point for monitoring the state-of-the-art in science and technology, and for making meaningful retrospective analyses. Yet no classification system will provide us with a real time structure and, most of all, it remains an imposed, database-dependent structure. How can we tackle this problem?

In this article we investigate the application of a new approach to a relatively small but rapidly growing research field - neural networks. This field is particularly convenient for our exploration because of its strongly emerging and expanding character. Debackere and Rappa (1994) investigated the field of neural network research from the viewpoint of the research community. Debackere and Clarysse (1997) extended this approach, particularly the role of actor networking, to another field characterized by fast growth - biotechnology. McCain and Whitney (1991, 1994) investigated neural networks research through co-citation maps of the field. Hinze (1994a, 1994b) used co-word analysis to study developments in bioelectronics, an interdisciplinary research field with relations to neural network research.

It is almost impossible to give a description (particularly a division into subfields) of a rapidly expanding research field such as neural networks beforehand, although McCain and Whitney (1994) have done a major effort to accomplish it by including data from a survey among experts in the field. Still, we are almost forced to assess the structure of this field from year to year.

According to the above discussion, we propose a field-definition based on the present situation. This is done by letting the data themselves generate a structure, and, with that, define the subdivision of the research field into meaningful subfields. In order to study the evolution over time, the above self-organized definition of the present structure is taken as a framework for the past structure. We explore this evolution by monitoring the interrelations between research subfields and by zooming into the internal structure of each subfield.

Our approach is, in broad terms, as follows. First, we identify the subfields of neural network research by applying specific clustering techniques to characteristic data elements such as keywords and classification codes of documents. Second, the interrelations between these different subfields (clusters) are mapped on the basis of their similarities (in terms of characterization on the basis of classification codes). This procedure yields a coarse, overall structure of the entire field. Third, bibliometric maps of each subfield are separately constructed with help of specific co-word techniques. The overall structure, together with these detailed subfield maps (fine structure), are used for monitoring the dynamical features of the entire research field. Furthermore, by determining the positions of main actors (universities, firms, countries, etc.) on the map, these structures can also be used to assess the activities of these main actors (see for instance, Hinze 1994b). We discuss such an actor assessment in a forthcoming article (Noyons & van Raan 1996).

Finally, we reverse our approach by analyzing the developments based on a structure generated in the past. Thus, we explore the potential of our method to put the observed actual developments into a possible future perspective.

6.3 Methodological principles

First of all, we have to make a choice of the benchmark year - i.e., the year we use as a starting-point of our analysis. As discussed above, this benchmark-year may be the current or a (very) recent year (the present), or some years ago ('the past'). As the methodological principles are independent of the chosen benchmark year, we simply call this year ***t***.

For this year ***t*** we identify the most important research topics in the field, by making a frequency analysis of classification codes or keywords, i.e., the number of publications with these codes or keywords. In fact, each publication can be regarded as a building block represented by a string of classification codes or keywords. Second, we analyze the number of times each possible pair of codes or keywords co-occurs in a publication. The resulting co-occurrence matrix is the input for a cluster analysis. Codes or keywords that are often mentioned together in the same publications are more likely to be clustered than those that hardly ever or never co-occur. The resulting clusters are supposed to represent a meaningful subdivision of the research field in terms of relevant subfields for the chosen year ***t***. The advantage of such an approach is the possibility it gives to analyze the structure, independent of database classification systems (although the data elements used for structuring, such as classification codes, are provided by the database). In short, we let the structure emerge from the data. Any science or technology field can be structured (i.e., the relevant subfields and their relations can be identified) as long as documents (articles or patents, and their content-describing data elements) are available for the above types of analysis. The interaction between these subfields, and hence the change or dynamics of the field's internal structure, can be monitored over a period of time. Such changes may point to important developments. From the above, it is clear that we have given up the idea of presenting the whole field with as much as possible detail in just one map. Our experiences in many mapping studies show that it is better to create an overview map along with detailed maps for each of the subfields.

In this study, we use the co-occurrence of classification codes to make the coarse overall structure for the overview map, and the co-occurrence of keywords to make the detailed maps of the different subfields. In the following, we briefly sketch the main elements of this procedure. For the proposed procedure we have to start, as discussed in the introduction, with a first selection-step to define and delineate the field and to collect all publications (of the chosen year ***t***) covered by this selection.

This first selection-step is made by simply using the keyword "neural net-" (as controlled term, uncontrolled term, title word, or classification code) in the INSPEC database. A classification code frequency analysis of the publications generated by this first selection-step revealed about 90 of these codes.

After delineation of the field, relevant elements have to be extracted from the publication data. In INSPEC there are several data elements which are important for our study: title words, abstract words, controlled terms (thesaurus terms or indexed terms), uncontrolled (free) terms, and classification codes.

In principle, all these data can be (and have been) used for bibliometric clustering and mapping. The choice of a particular data element is dictated by the specific objectives of a study. As discussed above, for the creation of the coarse overview structure, we used the classification codes. These codes from INSPEC's *Physics Abstracts Classification Scheme* provide a first description of the main contents or scope of a publication. As discussed earlier, their disadvantage in terms of conceptual rigidity at the same time, gives a certain advantage in terms of keeping the global structure relatively stable over time. Since the more topical characteristics of the field are to be represented in the detailed subfield-maps, we use keywords to create these maps.

The main methodological steps in the cartographic procedure are as follows. First, a specially designed cluster analysis is applied to the matrix containing the co-occurrences of the previously discussed 90 classification codes in neural network research (publications in year ***t***). In this first step, we deal with lower level linkages, i.e., the similarity of individual publications represented as strings of classification codes. We normalized this 90*90 co-occurrence matrix using the Salton-index (see, for instance, Peters & Van Raan 1993a, 1993b). This normalized matrix was used as the input for a cluster analysis (SPSS, waverage). We developed an algorithm to perform a series of clusterings at varying thresholds for the distance (i.e., a spatial representation of the similarity-measure) with which two elements are clustered in a hierarchical configuration. Thus, we determined empirically the number of clusters as a function of the distance-threshold (see Braam, Moed & Van Raan, 1991a, 1991b). If there is a plateau in this function, then we have a stable region where relatively large changes in the distance-threshold do not change the number of clusters. Although a typical plateau was not found, the function showed a significant curvature (for more details, see Noyons & Van Raan 1995). We chose to cluster at that point, which yielded 18 clusters. We define these clusters as subfields originating from classification code linkages in publications in year ***t***. Very recently, we found that a novel procedure to create a spatial (topological) representation of similarity-relations with the help of neural networks (Kohonen-type) yields a distribution which is very similar to the distribution obtained with the above described plateau-method. Therefore, we feel confident that the resulting clusters represent a reasonable division of the field as whole. The comparison of the clustering method described in this paper with the method based on the application of Kohonen-type neural network is discussed in a forthcoming paper (Moll, Noyons & Van Raan, 1996).

The structure is completed with the construction of a bibliometric map for year ***t***. As the subfields are clusters of classification codes, publications may belong to more than one subfield. This phenomenon introduces linkages at a higher aggregation level: The clusters can now be regarded as strings encoded by publications. Thus, a publication co-occurrence matrix for the 18 subfields can be constructed, and used as an input for multi-dimensional scaling (MDS). This technique puts the 18 subfields into a two-dimensional representation, in such a way that subfields with a high similarity (as columns or rows in the 18*18 matrix) are positioned in each other's vicinity. Subfields with a low similarity (i.e., with just a few or no publications in common) are more remote from each other. Thus, the spatial distance represents the relatedness of the subfields. It should be noted that a complete representation of all subfield-relations would require a 17- (18 minus 1) dimensional representation. In the constructed map these relations are projected into two dimensions, and consequently they will not all be represented optimally. Therefore, we enhanced the map with lines between subfields which have a relatively strong direct relation. Generally, however, the 'explained variance' in our maps based on the clustering-MDS combination is at least 80%. This means that our two-dimensional map represents, by far, the largest part of the structural information (an alternative approach is discussed by Kopcsa & Schiebel 1998).

Comparison of the field structure for a series of successive years (***t***, ***t + 1***, ...) enables us to study the changes of research focus, in general, and of interactions between specific subfields, in particular.

6.4 Putting a time reference into the mapping procedure

Earlier we mentioned the rigidity of database classification systems. However, it is clear that from time to time the classification system has to be adjusted by the database producer. This phenomenon may introduce a staccato character to the controlled-term-indexing and classification-scheme modification processes. For instance, the introduction of new terms and codes, as well as adjustments in the existing classification schemes, artificially affect the structure of the field, especially in rapidly developing fields like neural network research [7]. This is particularly the case if classification codes are split into two or more components. These new codes may not remain in the same cluster as the parent code, often because changes in the fine structure of a field are triggered by broader developments.

Such abrupt changes often make it difficult to compare structures, based on co-occurrences of classification codes, over successive years, even if a "roof-tile"-like mapping method (based on overlapping 2-year-blocks) is used. Therefore, we decided

[7] McCain & Whitney (1994) properly observe that an emerging interdisciplinary field has the disadvantage of poorly indexed bibliographic data, until new and proper descriptors and classification codes are established.

to take the structure in the most recent year - the present - as a starting point, and to observe how this structure behaves in preceding years. Thus we take (1) the present structure (year ***t***, e.g. 1995) of the field (in terms of subfields originating from the previously described clustering-procedure) as a basis for definition, and investigate changes in that structure back into the past, up to, for instance, year ***t-4***. As discussed above, this coarse structure is based on co-occurrences of classification codes.

In addition, we create (2) the fine structure of each of the subfields from year to year with the help of co-word analysis (for more details, see Noyons & Van Raan 1995).

By studying the temporal changes, we obtain an overview of the developments (the history) towards the present on the coarse as well as on the fine-structure scale. Thus, we analyze the history of each subfield in terms of the present viewpoint in neural networks research. It gives us the possibility to trace where important present-day developments had their origins. These might be far outside the field as it was perceived and defined at that time!

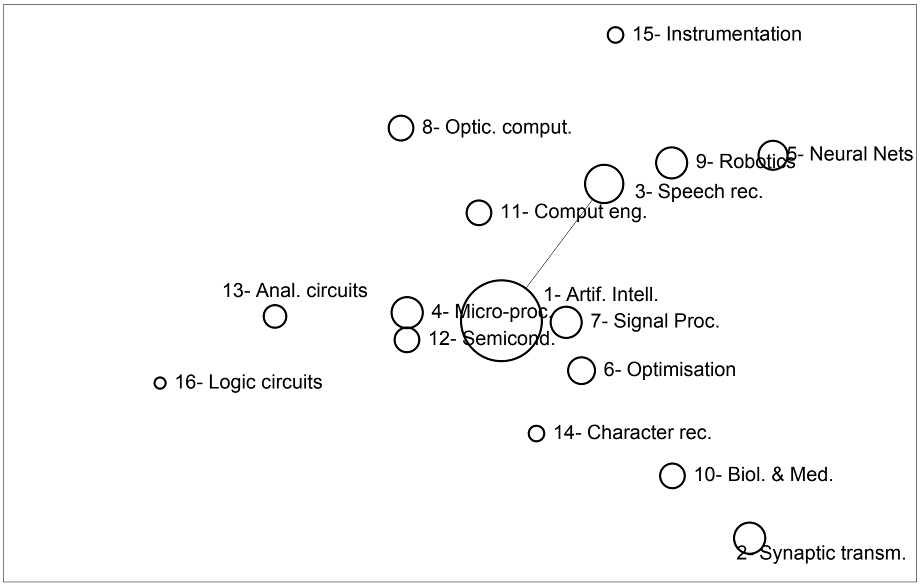
As an experiment we also explored the reverse procedure, in order to reconstruct the "real" present from the past. Here, the structure of the 'oldest' year (the past, e.g., ***t-4***) is taken as starting point. Subsequently, interactions between and within subfields are examined for subsequent years (***t-3***, ***t-2***, ***t-1***, ***t***). We claim that the results thus obtained for the most recent year (***t***) foreshadows the "real" present structure. In the same way, findings in the most recent structure may foreshadow developments in the near future. The fascinating point here is that the "real" present state-of-the-art may differ considerably from the "foreshadowed" state-of-the-art. This means that dead end developments (in the recent past) can be identified. Thus, our approach opens up new avenues for analyzing specific successful trajectories of scientific or technological progress. In the following section, we focus on the first explorations of this kind.

In any assessment of the role of actors (universities, firms, countries, etc.), the application of this self-organized structuring based on a fixed framework of subfields during the studied period, provides a reasonably reliable overview and is therefore essential. We focus on that topic in a forthcoming article (Noyons & Van Raan 1996).

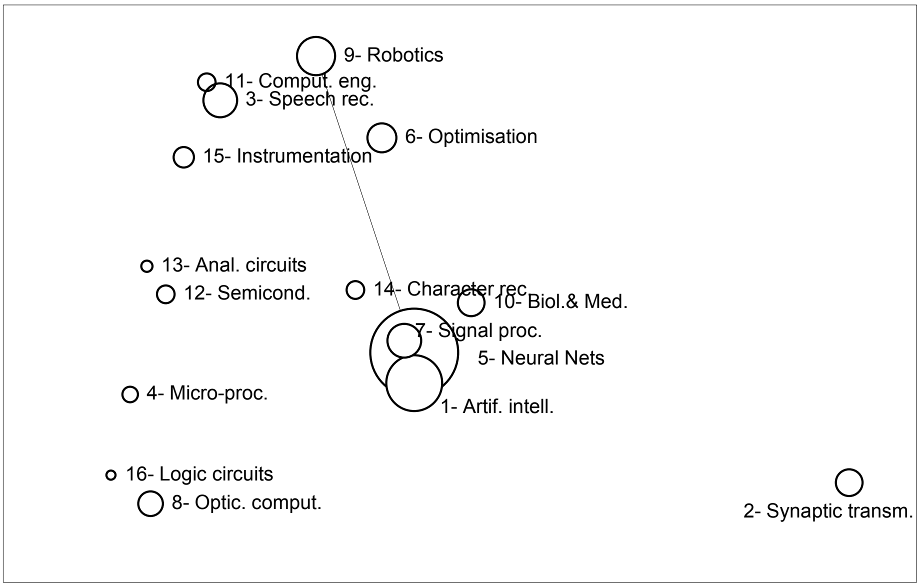
6.5 Results and discussion

6.5.1 Observations with the overview map: the 'coarse structure' of the field

First, we discuss the "back to the future" approach in which the structure is determined in the past (e.g. year ***t-4***). We examine how this structure behaves in subsequent years, and particularly in the most recent years of this study. As discussed in the previous section, the definition of the subfields is generated by applying a cluster-analysis to 90 classification codes. In order to follow temporal developments in a smooth way, we introduced a "roof-tile" approach of successive, overlapping 2-year blocks. Thus, instead of one starting year (e.g., ***t-4***), we start with the 2-year block {***t-4***, ***t-3***}, which in this case is {***1989***, ***1990***}. For these starting years, our cluster analysis yielded 16 clusters of classification codes (i.e. the ‘1989/1990-subfields’). The codes in these clusters allow us to recall the publications contained by the subfields. Thus, all neural network research papers from 1989/1990 are assigned to the identified subfields. In the next step, all 1992/1993 neural network publications, are assigned to the 1989/1990-based subfields on the basis of their 1992/1993 classification-codes. Based on the similarity of subfields as reflected in common publications, we can then create the structure of neural network research for 1992/1993 based on subfield-definitions of 1989/1990. This is an example of what we mean by structuring the present on the basis of the past. The results of this "from past to present" approach are shown in Figure 1. In the 1989/1990 map of the field (Figure 1a), the subfields are distributed relatively homogeneously over the map. The names were derived from the most frequent classification code(s) of the subfield concerned. The numbers correspond to the size-ranking of the clusters in 1989/1990. The surface area of the clusters is (approximately) proportional to the number of publications. There is one central subfield (no. 1: Artificial intelligence), and several other subfields are in its direct vicinity. Furthermore, there are peripheral subfields: synaptic transmission (no.2), biology and medicine (no. 10), instruments (no. 15), and logic circuits (no. 16). Now we look at the map for 1992/1993, based on 1989/1990 structures as discussed above (Figure 1b). This shaping of the present with a past framework clearly leads to specific patterns, namely a quite inhomogeneous distribution of subfields. The present is not such that subfields have been merged, thus showing very little differentiation. We see that the structure has changed significantly. Subfield 5, neural networks, has taken over the central position in the field, in combination with artificial intelligence (no.1) and signal processing (no. 7). Also biology and medicine (no. 10) moved to the center. Other subfields have become smaller, and seem to have been pushed away from the center to the periphery. In particular, subfield 2 (synaptic transmission) has now become an isolated outer province on the right-hand side of the map.



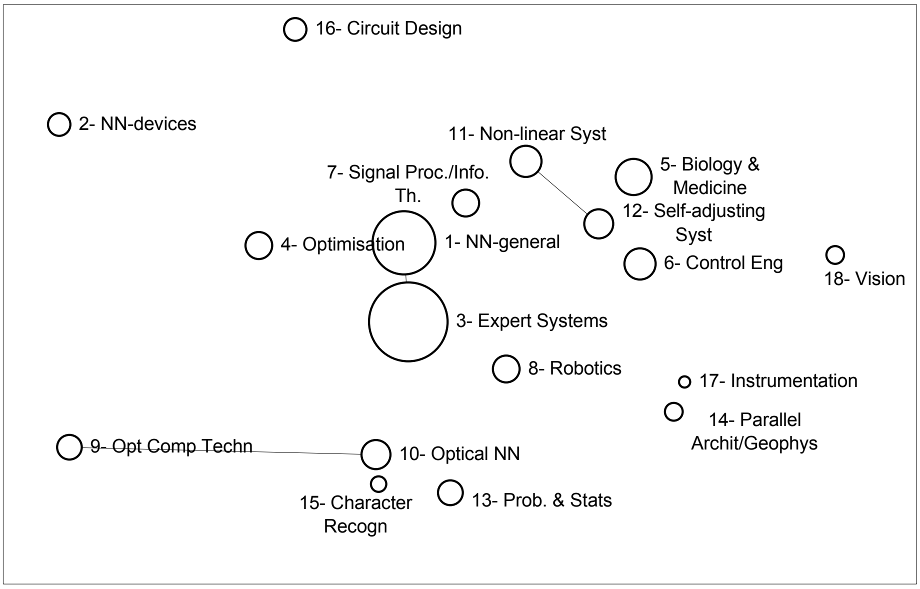
(a) 1989/1990 based on 1989/1990 data



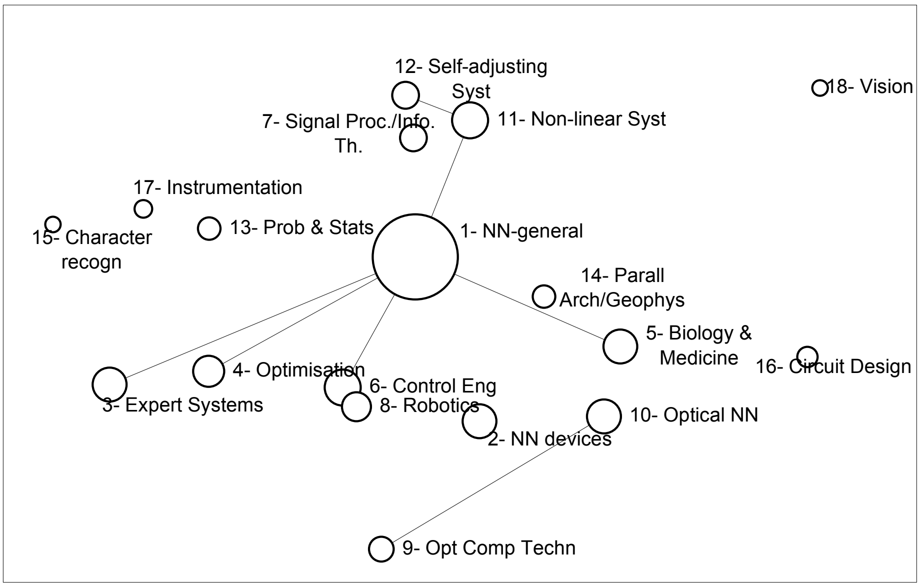
(b) 1992/1993 based on 1989/1990 data

2-dimensional representation of sub-fields. Definition of sub-fields based on clusters of the most important classification codes in 1992/1993. Cluster size (surface area) represents the proportion of publications included in each sub-field. Lines between sub-fields indicate relatively high number of 'common' publications.

Figure 6-1 Neural Network Research Maps (a: 1989/1990 and b: 1992/1993)



(a) 1989/1990 based on 1992/1993 data



(b) 1992/1993 based on 1992/1993 data

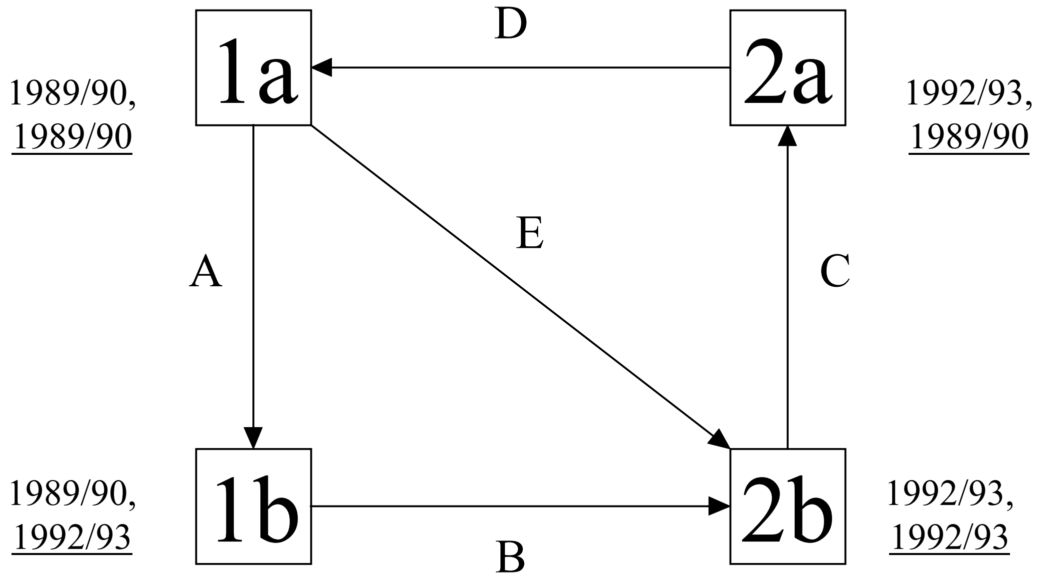
2-dimensional representation of sub-fields. Definition of sub-fields based on clusters of the most important classification codes in 1992/1993. Cluster size (surface area) represents the proportion of publications included in each sub-field. Lines between sub-fields indicate relatively high number of 'common' publications.

Figure 6-2 Neural Network Research Maps (a: 1989/1990 and b: 1992/1993)

In order to discuss the observed phenomena in more detail, we also look at the "other-way-around" procedure - i.e., from present to past. First, a similar procedure as above, but now with the classification codes of the 1992/1993 publications, was used to generate the 1992/1993 subfields. As discussed in the foregoing section, we identified 18 clusters (the 1992/1993 subfields). Subsequently, this subfield structure was applied to the 1989/1990 articles. Figure 2 shows the two resulting maps: Figure 2a presents the map of 1989/1990 based on the 1992/1993 structure, and Figure 2b the 1992/1993 map, also based on the 1992/1993 structure. As the subfield-numbering scheme corresponds to size-ranking, the numbers are not the same as in Figure 1, since the clustering algorithms of 1989/1990 and of 1992/1993 obviously yield different results. Also, the contents of the clusters are different from those of 1989/1990 as is clearly demonstrated by the names of the subfields. The subfield 3 (expert systems) occupies a central position in 1989/1990, but not in 1992/1993. We see that this phenomenon is related to similar findings with Figure 1. We also observe that this dramatic change in the positioning of subfield 3 does not greatly influence the position of other subfields.

Our conclusion is that the method in which the subfield structure is derived from the present data, is better suited to our purposes. The reason is the following. One of the objectives in a time-dependent analysis is to visualize developments in the field and to see how subfields interact. In Figure 1 (from past to present), the most visible trend is the after effect of the paradigm shift from artificial intelligence to neural networks. This approach appears to structure the present situation without sufficiently taking recent developments into account. Figure 1 shows that the map of 1992/1993 is heavily dominated by just three or four central subfields: their size increases, and their position becomes more central. Figure 2 suggests that this is not the actual situation. Here, not only is the present situation described more accurately (which is obvious, of course, as we use the 1992/1993 data to structure the 1992/1993 map), but we also observe a structure for the past, which allows all subfields to obtain their own position (without being dominated by others).

An additional advantage of the from-present-to-past approach is found in the application to actor analysis (see our forthcoming article Noyons & Van Raan 1996). By starting to position the activity of actors (countries, organizations, firms, etc.) within the present situation, we can place the assessment of the activity of these actors in the past in perspective. For instance, suppose an actor is very active in a particular subfield which has become important very recently. Moreover, this actor was already active in that subfield 5 years ago. But the subfield as such was not identified on the map at that time (for instance, because it was too small). Thus, if the structure of that year is derived from data of that year, this (sub)field would not have been identified, and the remarkable performance of the actor would not be recognized as taking place in a specific, evolving part of the field. In the from-present-to-past approach, we immediately observe that the actor has been on this (promising) track all along. As a result, the method identifies actors that may determine future developments in the field.



Part 1a: Map based on 1989/1990 data; subdomain definition based on 1989/1990 data
Part 1b: Map based on 1992/1993 data; subdomain definition based on 1989/1990 data
Part 2a: Map based on 1989/1990 data; subdomain definition based on 1992/1993 data
Part 2b: Map based on 1992/1993 data; subdomain definition based on 1992/1993 data

Figure 6-3 Schematic representation of the transformations and comparisons between Figs. 1 and 2 (for further explanation, see text)

The mutual relations of the maps in Figures 1 and 2 are schematically depicted in Figure 3. With help of the transformation and comparison channels indicated by ***A***, ***B***, ***C***, ***D***, and ***E***, we can summarize the previously discussed mapping approaches.

- Figure 1a is the map of 1989/1990 based on the structure of these years (the real past), and ***A*** represents the transformation of this 1989/80 structure for 1992/1993 (from 'past to present' or: 'the present as constructed from the past'), which is mapped in Figure 1b;
- Figure 2b is the map of 1992/1993 based on the structure of these years (the real present), and ***C*** represents the transformation of this 1992/1993 structure for 1989/1990 (from present to past or: the past as constructed from the present), which is mapped in Figure 2a;
- Consequently, ***B*** represents the comparison between the present as constructed from the past (1b), with the real present (2b); ***D*** represents the comparison

between the real past (1a), with the past as constructed from the present (2a); and ***E*** is the comparison between real past (1a) and real present (2b).

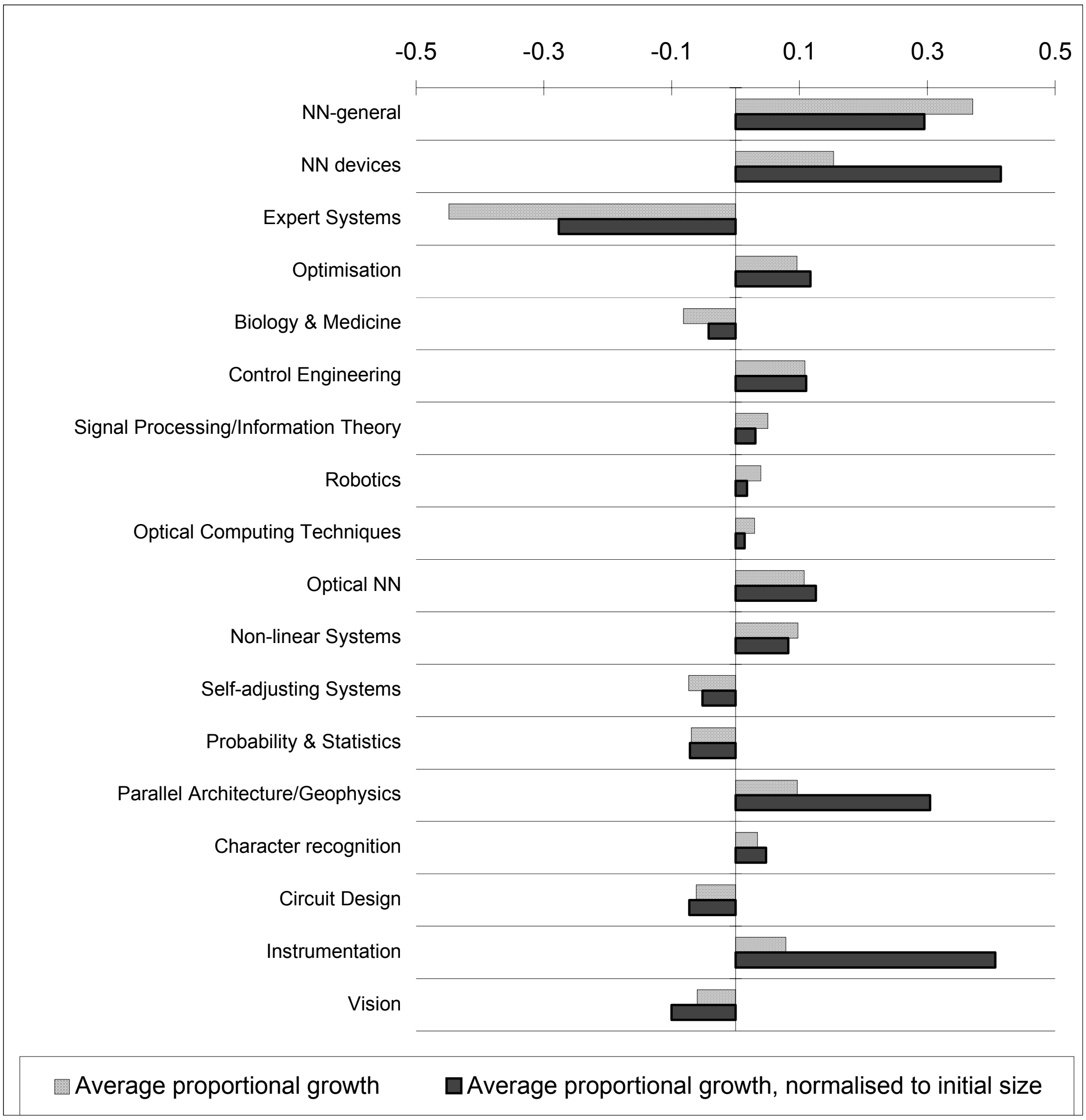
We think these transformations and comparisons have interesting potentials as devices to identify successful pathways or dead end trajectories, and, in addition, to identify leading actors in the field, pointing to future developments. We therefore intend to apply this approach in current work for further testing and improvement.

In this paper, we report some first observations using examples. In the ***D***-comparison, i.e. the comparison between real past (1a) with the past as constructed from the present (2a), we see that in the real past speech recognition is positioned in the vicinity of robotics and computer engineering (1a). In the reconstructed past (2a), speech recognition is not present as a separate cluster but is integrated in non-linear systems (in one cluster), which is very close to self-adjusting systems. In fact we see that the past is reinterpreted in terms that are now more topical. Similarly, a reconstruction is also visible for the development of hardware. In the real past we find a group of clusters for logic circuits, analogue circuits, microprocessors, and semiconductors, whereas in the reconstructed past these developments are simply reduced to neural network devices and circuit design.

Although the subfield (cluster) of synaptic transmission does exist in the present as constructed (***A***-comparison) from the past (1b) - and is, of course, already there in the 'real past' (1a) - it has disappeared in the real present (2b) (***B***-comparison), and it is also not re-constructed (***C***-comparison) anymore in the past as constructed from the present (2a) (both the ***D***- and ***E***-comparison).

It should be noted that the discussed method requires that the structure of the field (based on the identification of subfields) is revised each year. As a consequence, the structure used to evaluate the past will be continuously adjusted, so that the past performance will be put into new perspective each time the structure is updated.

In Figure 4 an overview of the evolution (i.e., the change in the number of publications) of the subfields is given, applying ***C***-comparison. We used two indicators: (1) the square root of the average difference in the number of publications between 1989/1990 and 1992/1993, and (2) the average difference in the number of publications between 1989/1990 and 1992/1993, normalized to the size of a subfield in the first period. The latter indicator enhances the trends for the smaller subfields.



Change in numbers of publications per sub-field in 1992/1993 as compared to 1989/1990.

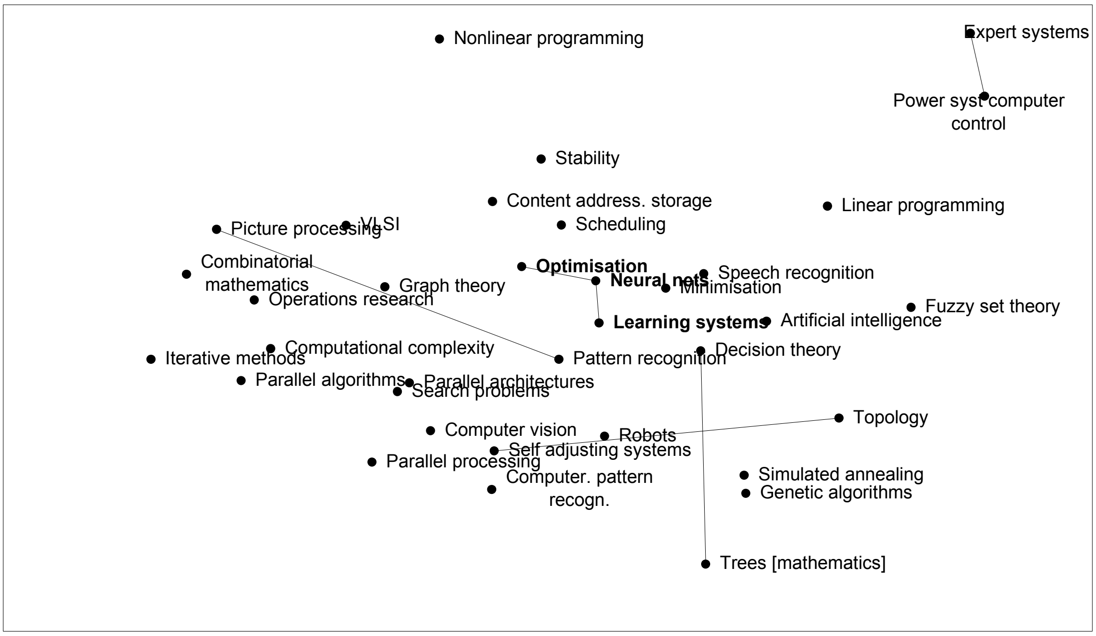
Figure 6-4 Evolution of sub-fields in Neural Network Research from 1989/1990 (based on 1992/1993 data) to 1992/1993

The dark Grey bars in Figure 4 show that there is a sharp increase in publication activity (numbers of papers) for neural networks (general). At the same time, there is a sharp decrease of number of papers in expert systems. These two observations are strongly related to each other. As we are dealing with a relatively young and 'expanding' research field, the observed phenomenon is mainly induced by a change in terminology. This process is also illustrated by Figure 2: Subfield 3, expert systems, has a central position in 1989/1990, together with neural networks (general). In 1992/1993 this subfield is pushed away from its central position 1989/1990 to a less central position in 1992/1993, in the vicinity of optimisation, robotics, and control engineering, which is indeed nowadays a typical environment for expert systems. At the same time, the central position within the field as a whole has been taken over by neural networks (general). An interesting finding (Figure 2) is that three closely related subfields (self-adjusting systems, non-linear systems, and signal processing/information theory) have moved from the center to the upper part of the map. This may point at a tendency towards a more independent (separate) position in the field. We further observe (from the light Grey bars in Figure 4) a significant increase of activity in neural networks devices, parallel computing/geophysics, and instrumentation.

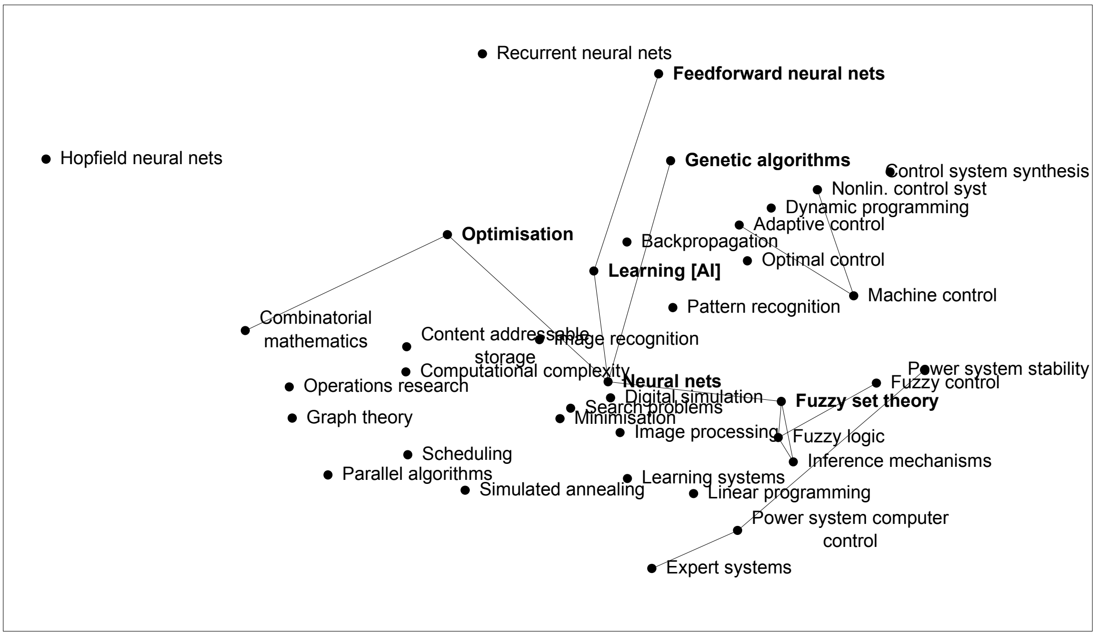
6.5.2 Observations with the detailed subfield-maps: the fine structure of the field

The mapping approach discussed above is concerned with the macro level. In principle, a similar approach can be applied to the micro level. We believe, however, that the technology of the approach has to be improved further, particularly in terms of automation. Therefore, in this paper we confine the presentation of micro level mapping to comparison of the real past with the real present, i.e., comparison ***E***. To monitor developments in neural network research in more detail, we constructed 'fine structure' maps of the subfields. This was accomplished by a comparison of co-word maps (using controlled terms) based on publications from the subfields (defined by the 'present') in 1989/1990 and 1992/1993. In this article, we confine ourselves to the presentation of one example: The subfield optimization (no. 8). The maps for this subfield are presented in Figure 5a (1989/1990) and 5b (1992/1993). The entire fine structure, i.e., the complete set of subfield-maps, is presented in Noyons & Van Raan (1995) [8].

[8] This report is also presented on the CWTS homepage on Internet/WWW at http://sahara.fsw.leidenuniv.nl/cwts/cwtshome.html.



(a) 1989/1990



(a) 1992/1993

Topics included concern > 2% of the publications in this sub-field. Topics in bold face concern > 10% of the papers. Lines indicate a relatively strong direct link between topics (Salton Index > 0.3).

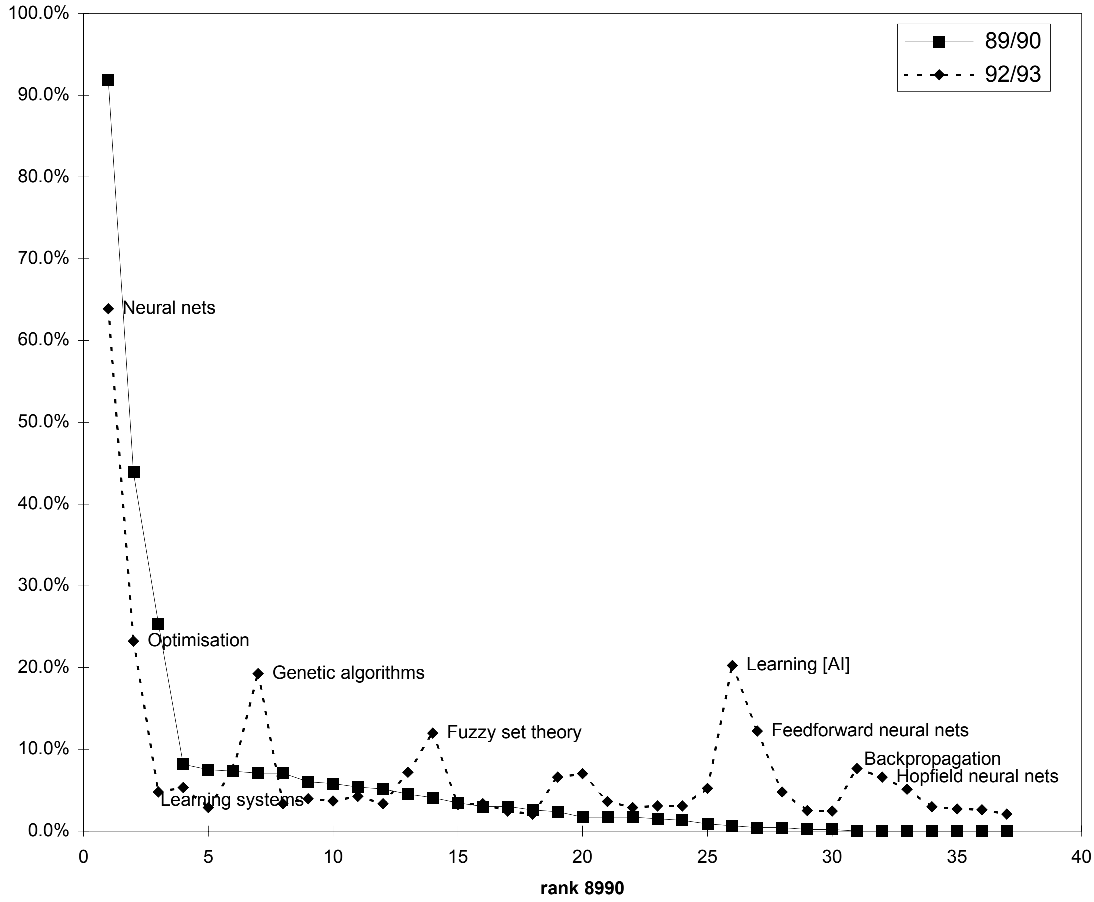
Figure 6-5 Maps of sub-field 'Optimization' (a:1989/1990, b:1992/1993)

Very clearly, there appears to have been major developments in the subfield. For instance, nonlinear techniques and control systems merged, and work on fuzzy set theory also developed primarily in relation to control systems. As in all other subfields, we see that the application-orientation of neural network research increased dramatically.

Currently, we are improving the co-word mapping technique considerably by applying automated natural language analysis (syntactic parsing) in order to generate keywords directly from the publication text itself (e.g. the abstract). The use of controlled or uncontrolled terms as given by the database producer may then come to an end. First results (concerning Figure 5b, subfield optimization, 1992/1993) show a major improvement (with a richer map, and more pronounced clusters) compared with the mapping work so far. We refer to a forthcoming publication (Moll, Noyons & Van Raan, 1996) for a more detailed discussion.

In Figure 6 we plot the relative number (frequency) of 1989/1990 publications for each of the 40 most prominent (i.e., most frequent) keywords, in the subfield, against ranking. This 1989/1990 frequency-rank distribution is given by the rapidly decreasing curve. Next we determined, for the same 40 keywords, the relative number of publications in 1992/1993. These data are also plotted in Figure 6, but we leave the ranking of keywords unchanged. This means, that an emerging topic immediately manifests itself as a peak: It keeps its old ranking of 1989/1990, but its relative frequency is much higher than in 1989/1990. Thus, the peaks in Figure 6 indicate the research topics found in an increasing number of publications. The valleys show the topics with a decreasing interest (at least in terms of publication activity). In this way we can identify hot and cold topics, as viewed from present[9]. We observe an increasing interest in genetic algorithms. We believe that the decrease of ‘learning systems’ and the increase of learning (AI) maybe due to an adjustment in the thesaurus of INSPEC. Furthermore, we believe that the decrease of neural nets is due to the introduction of more specific controlled terms by INSPEC. Here again, co-word structures based on parsed terms generated by syntactic analysis will improve the mapping methodology considerably.

[9] These can be indicated on the most recent map. We refer to the WWW-homepage mentioned in the previous footnote where these topics are shown in red and blue colors, respectively.



Topics are ranked in decreasing frequency order of 1989/1990. Points on the solid line indicate the proportion of papers on the most frequent topics in the sub-field. Points on the dashed line indicate the proportion of papers on the same topic, but now for 1992/1993. For further explanation: see text.

Figure 6-6 Evolution of central topics in sub-field 'Optimisation'

We discussed the results of our study with three researchers in different neural network groups (or work closely related to neural networks). The researchers are considered to be among the top researchers in Dutch neural network research. We sent them the full report by mail and asked them to comment on the results concerning the general developments in the field (overview map), and, in particular, on specific, significant details (fine structure maps). Given the small number of experts and the quite general questions we asked, this approach is only a first exploration and certainly not an extensive validation (see, for instance, Peters & van Raan, 1993b). Nevertheless, it is our experience that discussions with a few experts already reveal many important features. One of the experts pointed out that our study is based on data which may no longer correspond to the present situation. He mentioned that in many research fields a delay of 2 years between submission and publication in journals is not uncommon. He argues that this will have its effect on the results. As an example he mentioned the observed increase of activity for the topic "Hopfield Neural Nets". For the role of this research topic, we refer to Noyons and Van Raan (1995) where this topic can be found in the central subfield (no. 1) and in almost all other subfields: Non-linear systems (no. 2), control engineering (no. 3), neural network devices (no. 5), optical neural networks (no. 6), optimisation (no. 8), signal processing (no. 10), optical computing techniques (no. 12), parallel architecture (no. 13), probability ands (no. 14), circuit design (no. 15), and character recognition (no. 17). The expert stated that this particular type of neural network has lost the interest of researchers in the most recent years due to storage capacity limitations. This decline will not be directly visible because of publication delay. This 'handicap' for bibliometric studies is a quite general one, and has often been observed and discussed before. We stress, however, that this does not diminish the strength of bibliometric methods as such, but rather points to the need to apply these methods to publication data at a stage as early as possible, e.g., the electronic versions available at the publisher long before the publications actually appear. In another study of this kind (Noyons, Luwel & Moed, 1995), researchers in the field concerned (micro-electronics) pointed out that publication delay is particularly problematic for articles submitted to (international) journals. They stated that the delay between research and publication is significantly smaller where proceedings of conferences are concerned. This may force us to distinguish analytically between journal articles and proceedings as far as publication date is concerned. Another option is to take the submission date of a publication as a time indicator. Once electronic publishing with pre-print facilities becomes more common, the delay problem should become much less serious.

Another issue we discussed with experts is the choice of the data elements describing the contents of papers, used to structure the data. The classification codes we used for our overview map are from the Physics Abstracts Classification Scheme (PACS). This scheme, as well as the index of controlled terms in INSPEC, are subject to regular revisions. As such, revisions are supposed to follow developments in the field, but in fact they inevitably lag behind these developments. A fully up-to-date structure can only be obtained by (1) using as recent data as possible; and (2) approaching more closely the contents of the article as presented by the authors themselves. One possibility is to use the "uncontrolled terms" in the database, but a better approach, now currently being investigated by us, is to extract all important concepts (keywords, and keyword combinations) directly from the text.

6.6 Concluding Remarks

We consider the bibliometric approach described here with different past-to-present comparison modalities to be a novel tool for evaluation and monitoring studies. In the work presented, this approach has been applied to the field of neural networks research. On a larger scale, it creates the opportunity to structure the knowledge embedded in (very) large bibliographic databases and to make it accessible for analytic purposes. In particular, the dynamics of a given field can be visualized, especially in combination with the zoom-in function (switching from the macro to the meso level). Thus, on the basis of the most recent cognitive structure that we can reasonably obtain, predictions of developments in the short term are possible by extrapolating significant trends in changing patterns. Furthermore, comparison of the real present and the present constructed from the past (as described above) may provide new insight into successful as well as unsuccessful developments trajectories.

In addition, the approach enables us to obtain an interesting view on the history of the activity of a country (a university, or an industrial R&D division in a research field) as well as its present position. More specifically, this type of bibliometric mapping offers the possibility of analyzing activities on a more detailed level, for any actor in terms of subfields and over time; to characterize activities in relation to the identification of hot or cold topics (as viewed from the present); and to perform, in addition, impact analyses with an assessment of the strengths and weaknesses of the main actors in the field. As a result, these analyses identify actors in the field who have been ahead of their time, and thus maybe key-actors in the future.

We would argue that our approach is applicable to worldwide science and technology databases. If comparable or related descriptors of publication and/or patent contents are used or developed, the approach should be able to deal with any kind of database. It therefore also allows matching of publication and patent data, and exploration of the scope of different databases.

The described method requires that the structure of a field is revised each time a new analysis is conducted. This will put an actor's activity (and impact) in a new perspective every time more recent data is entered.

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7 Actor Analysis in Neural Network Research: The Position of Germany*

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Actor Analysis in Neural Network Research: The Position of Germany

Abstract

In this paper the results of a bibliometric study of neural network research are presented. This evaluative study includes bibliometric mapping and actor analysis of main players in the field on a macro level (countries, in particular Germany), and, on a lower level, of the main players in Germany. We found that Germany is among the leading countries in the field. This study, together with Noyons and Van Raan (1998), is also a blueprint for evaluative bibliometric studies of emerging or strongly developing science and technology fields. The monitoring of major developments in the field, and a detailed actor analysis were integrated into one study.

7.1 Introduction

This paper is a follow-up of Noyons and Van Raan (1998), in which we proposed a method to structure bibliographic data in order to evaluate a scientific field. In the present paper, we discuss the results of such a quantitative study.

The objectives of the study are (a) to generate an overview of the main and, in particular, the recent developments in the field, and (b) to identify and position the main German actors. The field under study is neural network research.

In our attempt to combine these two objectives, we found that they are in fact conflicting. The first requires that the structure is generated continuously each year, month, or whatever time unit. The changes in the structure from year to year are considered to represent cognitive processes going on in the field.

The second objective requires that the structure of the field remains unchanged during the whole period studied, in order to have some stability in the comparison of one year with another. More specifically, we want to compare the activity of actors from year to year. If the structure of the field differs for each year, so will the definition of the sub-domains. This makes it almost impossible to compare an actor's activity in year *t* with its activity in year *t+1*. Thus, we will not be able to determine whether the activity of an actor actually has increased in a particular sub-domain (see, for instance, Katz and Hicks 1995).

This paradox is addressed by adjusting the interpretation of the concept 'field dynamics'. The field dynamics we investigate, is restricted to the evolution of the sub-domains in a quantitative sense, and to the way they form a joint structure during the studied period. This structure is analyzed on the basis of a two-dimensional representation (a bibliometric map based on co-classification code analysis). The definition of the sub-domains (sets of classification codes) remains unchanged over the whole period of time. By 'zooming' into the individual sub-domains with co-word maps from year to year, we are able to monitor the dynamics on a smaller scale.

We let the bibliographic data itself generate the structure of the field ('self-organized mapping'). The question is: what data will we use to achieve this. In our foregoing paper (Noyons and Van Raan, 1998), we suggested that there are three options:

- Data of the whole period;
- Data from the first year of the period ('the past');
- Data from the last year of the period ('the present').

In this previous paper, we concluded that, for the kind of studies we are concerned with here, the latter is the best. Thus, the structure of the field (i.e., the definition of sub-domains in the field) was (and is) determined by the most recent data (the present). One of the crucial arguments for this choice is found in the application of bibliometric field structures for actor analysis. The activity of actors (countries, organizations, firms, and so on) within the present structure shows the actual, recent situation. If we take this present situation of a field as a starting point, and look at the activity of authors in the past 'based on the present', it will tell us something about the 'activity history' of those actors in relation to the most recent situation. For instance, if country A is very active in a sub-domain which has become important only recently (and not visible in the structure of five years ago), and if A was already active in this sub-domain five years ago, we conclude that A has been on this 'successful' track all along. If, however, the present structure is 'derived from the past' data, this sub-domain will probably not be identified, so that this remarkable past performance of A will not be recognized.

It should be noted that the proposed method requires that the structure of the field (identification of sub-domains) must be revised every year, because it must be based on the *present* data. As a consequence, this structure (sub-domain definition) used to evaluate the 'past' is adjusted as well, so that the past performance will be viewed from a new perspective each time the structure is 'updated'.

7.2 Method

The field neural network research is represented by all publications in INSPEC (1989-1993) containing the truncated term "NEURAL NET" in any bibliographic field (title, abstract, controlled terms, uncontrolled terms or classification codes). We found in total 21,437 publications. By using the INSPEC database, we restrict ourselves to the physics and computer-engineering-related research of neural networks.

We identified 18 sub-domains of the field by determining clusters of the most important (that is, the most frequent) classification codes attached to the publications. These clusters were determined by cluster analysis applied to the co-occurrence matrix of 90 selected classification codes (see Noyons and Van Raan 1998). The definition of the 18 sub-domains is given in Table 7–1.

Table 7–1 Definition of 18 sub-domains in neural network research by classification codes (1992/1993)

Cluster number	*Number of pubs*	*Classif. Code*	*INSPEC Code Description*
1	967	B6140C	Information/communication theory; Optical information and image processing
1	6130	C1230D	System theory & cybernetics; Neural nets
1	1474	C1240	System theory & cybernetics; Adaptive system theory
1	1539	C1250	System theory & cybernetics; Pattern recognition
1	1289	C5260B	Computer vision and picture processing
1	4728	C5290	Neural computing techniques
2	91	A8732S	Psychophysics of vision, visual perception, binocular vision
2	176	B6120B	Information theory; Modulation methods; Codes
2	330	B6130	Information/communication theory; Speech analysis and processing techniques
2	270	C1220	System theory & cybernetics; Simulation, modelling and identification
2	109	C1330	Optimal control
2	249	C1340K	Nonlinear systems
2	236	C4130	Interpolation and function approximation
2	81	C7120	Computer applications; Finance
2	105	C7410D	Electronic engineering
3	145	A8730E	External and internal data communications, nerve conduction and synaptic transmission
3	122	A8770E	Diagnostic methods and instrumentation
3	87	C4220	Automata theory
3	99	C4240	Programming and algorithm theory
3	362	C7410B	Power engineering
3	613	C7420	Control engineering
3	90	C7440	Civil and mechanical engineering
4	161	B1285	Analogue processing circuits
4	628	C1290L	Application of systems theory; Biology and medicine
4	155	C3120C	Spatial variables
4	395	C7330	Computer applications; Biology and medicine
4	64	C7450	Chemical engineering
4	67	C7460	Aerospace engineering
5	157	B0260	Mathematical techniques; Optimisation techniques
5	62	B1265F	Microprocessors and microcomputers
5	827	B1295	Electronic circuits; Neural nets
5	89	C5160	Computer hardware; Analogue circuits
5	597	C5190	Computer hardware; Neural net devices
5	73	C7310	Computer applications; Mathematics
5	158	C7480	Production engineering
6	363	A8710	General, theoretical, and mathematical biophysics

Cluster number	*Number of pubs*	*Classif. Code*	*INSPEC Code Description*
6	134	B4120	Optical storage and retrieval
6	361	B4180	Optical logic devices and optical computing techniques
6	121	B4350	Holography
6	62	C1110	Algebra
6	131	C4240P	Parallel programming and algorithm theory
6	353	C5340	Associative storage
6	70	C6180N	Computer software; Natural language processing
7	83	A4230S	Optical information; Pattern recognition
7	238	C1230	System theory & cybernetics; Artificial intelligence
7	417	C4210	Formal logic
7	768	C6170	Computer software; Expert systems
8	297	C1160	Combinatorial mathematics
8	712	C1180	Mathematical techniques; Optimisation techniques
8	150	C3340H	Electric systems
9	89	A8730C	Biophysics; Electrical activity
9	70	B4270	Integrated optoelectronics
9	79	B7510B	Biomedical engineering; Radiation and radioactivity applications
9	395	C3390	Robotics
9	189	C7320	Computer applications; Physics and Chemistry
9	124	C7410F	Communications
10	317	B6140	Information/communication theory; Signal processing and detection
10	440	C1260	Information theory
10	173	C1310	Analysis and synthesis methods
10	278	C5260	Digital signal processing
11	283	C1250C	Speech recognition
11	78	C1340B	Multivariable systems
11	320	C1340E	Self adjusting systems
11	184	C5260S	Speech processing
11	98	C7430	Computer engineering
11	70	C7470	Nuclear engineering
12	159	B2570D	CMOS integrated circuits
12	159	B8110B	Power system management, operation and economics
12	379	C5270	Optical computing techniques
13	73	A8728	Bioelectricity
13	95	B7210B	Automatic test and measurement systems
13	273	C5220P	Computer hardware; Parallel architecture
13	66	C6130B	Computer software; Graphics techniques
13	101	C7340	Computer applications; Geophysics
14	299	C1140Z	Probability & statistics; Other and miscellaneous
14	132	C5320K	Optical storage
14	99	C5440	Multiprocessor systems and techniques
15	125	A8730	Biophysics of neurophysiological processes
15	63	B1130B	Computer aided circuit analysis and design
15	145	B2570	Semiconductor integrated circuits
15	107	C1320	Stability
16	94	B0240Z	Probability & statistics; Other and miscellaneous
16	68	B8110D	Power system planning and layout

Cluster number	*Number of pubs*	*Classif. Code*	*INSPEC Code Description*
16	74	C6185	Simulation techniques
16	106	C7410H	Instrumentation
17	235	C1250B	Character recognition
17	75	C5530	Pattern recognition and computer vision equipment
18	102	A8732E	Physiology of the eye
18	81	A9385	Instrumentation and techniques for geophysical, hydrospheric and lower atmosphere research
18	80	C5585	Speech recognition and synthesis

By using this scheme, we divided the neural network publications over 18 sub-domains. Thus, each sub-domain is represented by a set of publications. A publication can be assigned to more than one sub-domain. Each sub-domains was labeled with a name, referring to most frequent classification codes. An overview of numbers of publications included per sub-domain per two-year block (overlapping two-year blocks within the period 1989 to 1993) is given in Table 7–2.

Table 7–2 Numbers of publication per sub-domain by year (1989-1993) in neural network research

Cluster number	*1989/ 1990*	*1990/ 1991*	*1991/ 1992*	*1992/ 1993*	*Sub-domain label*
1	2756	5836	8987	9190	NN-general
2	684	1159	1527	1508	Non-linear Systems
3	630	943	1248	1482	Control Engineering
4	934	1253	1463	1441	Biology & Medicine
5	335	924	1438	1329	NN devices
6	543	943	1280	1321	Optical NN
7	4297	3918	1931	1291	Expert Systems
8	465	739	973	1111	Optimisation
9	512	727	894	953	Robotics
10	477	851	1009	922	Signal Processing/Information Theory
11	614	907	1027	917	Self-adjusting Systems
12	378	480	600	696	Optical Computing Techniques
13	181	410	576	612	Parallel Architecture/Geophysics
14	394	534	586	547	Probability & Statistics
15	307	446	498	425	Circuit Design
16	90	203	295	353	Instrumentation
17	144	265	336	291	Character recognition
18	213	268	275	263	Vision
Total	5907	8841	10778	10439	

Subsequently, we counted the number of publications per country. A publication was assigned to a country on the basis the address of the *first* author[10]. The results per country by sub-domain were used to characterize the research profile of the most active countries in the field. For this purpose we used the 'activity index' (see Engelsman and Van Raan 1993, Noyons *et al*, 1994). This index normalizes the number of publications per country by sub-domain, to the activity of that country in the whole field, with a further normalization to the same ratio worldwide. A range of scores in the 18 sub-domains characterizes a country's activity in the field with respect to focus of attention ('preference').

The sub-domains, defined by clusters of classification codes, were monitored with respect to the joint structure they formed together during the period 1989 to 1993. This was done in the following way. We calculated the number of publications each sub-domain had in common with the others. The resulting co-occurrence matrix was input for multidimensional scaling (MDS). We constructed a map of the situation in 1992/1993, and another for 1989/1990. The differences between the two maps will give indications about the dynamics of the field on a 'macro scale'.

Next, we constructed 'fine-structure' maps of the sub-domains. The most frequent key-words were selected per sub-domain and used for co-word analysis. We constructed a map for the 'present' (1992/1993) and the 'past' (1989/1990). Moreover, we identified the 'hot' topics (words with a significantly higher frequency in the 'present' than in the 'past'), and the 'cooled-down' topics. Finally, we generated an overview of the most active German institutions by sub-domain.

7.3 Results

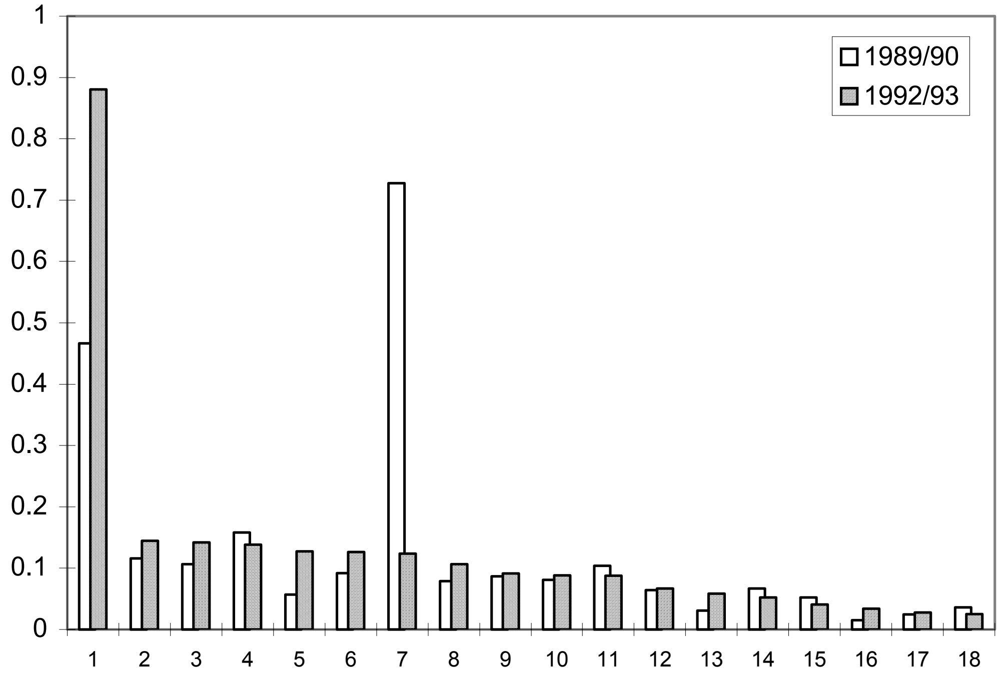
Neural network research has already been the subject of several studies (Debackere and Rappa, 1994; McCain and Whitney, 1994). This attractiveness is due to the interdisciplinary and relatively new character of the field and, most importantly, its strong growth and expanding application potentials. McCain and Whitney (1994) demonstrated what kinds of problems are encountered when exploring such a field. One of the main problems is that there are only a few accepted notions of the structure of the field: it is difficult to obtain an extensive overview of the main sub-domains.

The strength of our method is that it does not depend on these accepted notions. In fact, we let the bibliographic data generate its own structure of the field. We analyze its dynamics by the monitoring the evolution of the separate sub-domains and the relations among them.

We discuss in this paper the trends in neural network research only with respect to the size (numbers of publications) from 1989 to 1993. For other aspects (such as the

[10] Note that in the INSPEC database only the affiliation of the *first* author is included.

structural evolution of the field, that is, the relations of the sub-domains among each other) we refer to our foregoing article (Noyons and Van Raan, 1998). The 'size' of a sub-domain in a two-year period was determined by the proportion of publications included in that sub-domain in relation to the total number of publications in the same two-year period for the whole field. In Figure 7-1, these 'relative sizes' of the 18 sub-domains in 1989/1990 and in 1992/1993 are plotted.



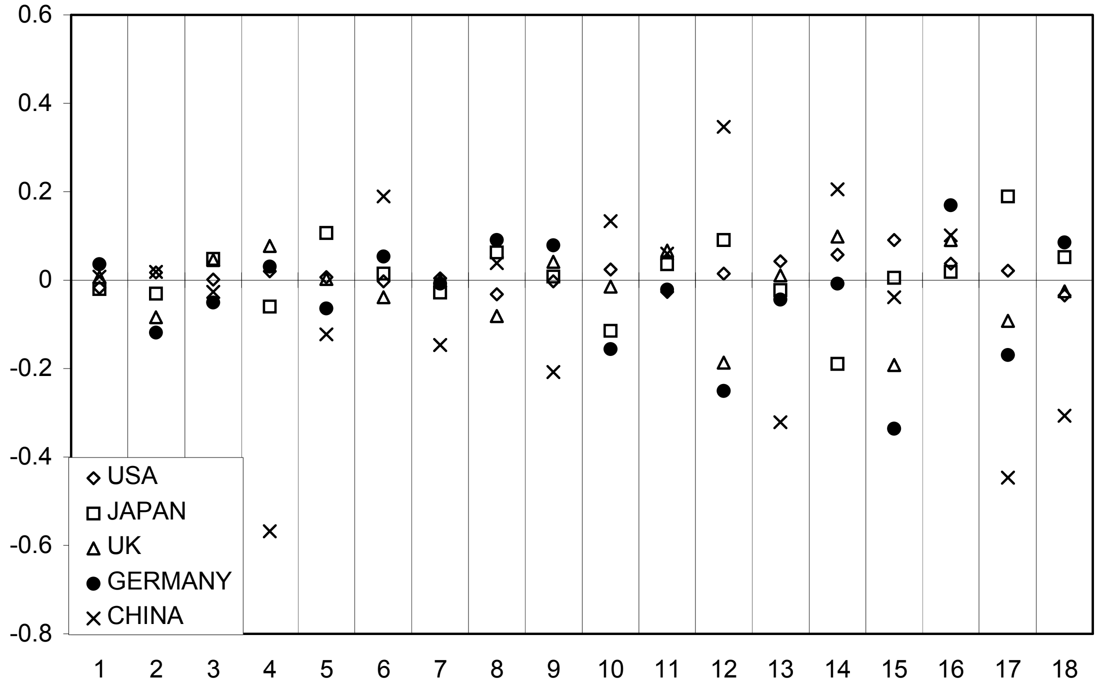
Sub-domains

1	NN-general	10	Signal Processing/Information Theory
2	Non-linear Systems	11	Self-adjusting Systems
3	Control Engineering	12	Optical Computing Techniques
4	Biology & Medicine	13	Parallel Architecture/Geophysics
5	NN devices	14	Probability & Statistics
6	Optical NN	15	Circuit Design
7	Expert Systems	16	Instrumentation
8	Optimisation	17	Character recognition
9	Robotics	18	Vision

Figure 7-1 Size of the 18 neural network research sub-domains in 1989/1990 and 1992/1993

We observed a significant *increase* of activity in sub-domain 1 (NN-general), 5 (NN devices), 13 (Parallel Architecture/Geophysics), and 16 (Instrumentation). A dramatic *decrease* of activity was observed in sub-domain 7 (Expert Systems). As pointed out in Noyons and Van Raan (1998), the 'shift of activity' from 7 to 1 and 5, is merely due to adjustments in the classification scheme of INSPEC. So, in fact, it is an artifact, based on 'jargon change'.

First, we give an overview of the activity profile of the most active countries in neural network research. For the most recent period of time in our study (1992/1993), the results for the five most active countries are given in Figure 7-2.



Sub-domains			
1	NN-general	10	Signal Processing/Information Theory
2	Non-linear Systems	11	Self-adjusting Systems
3	Control Engineering	12	Optical Computing Techniques
4	Biology & Medicine	13	Parallel Architecture/Geophysics
5	NN devices	14	Probability & Statistics
6	Optical NN	15	Circuit Design
7	Expert Systems	16	Instrumentation
8	Optimisation	17	Character recognition
9	Robotics	18	Vision

Figure 7-2 Activity Index in 1992/1993 for 5 most active countries in neural network research

We found that Germany was in this 'top' five in the whole period studied. The figure illustrates where a country puts its emphases, in relation to the activity of all other countries. Of course, the calculated activity indices are subject to (statistical) error.

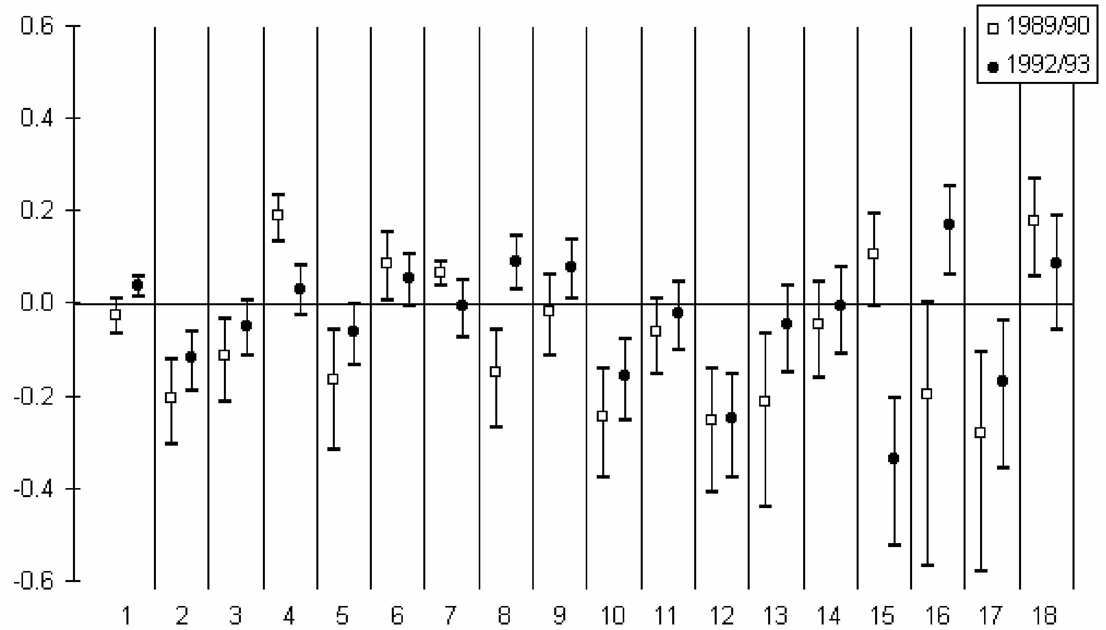
For the sake of clarity, we leave error-bars out of this figure (they will, however, be used in the other figures).

China has an activity profile that differs substantially from that of the other countries. For instance, in sub-domain 4 (Biology & Medicine) the Chinese activity is far below (worldwide) the average, whereas the activity in this sub-domain of the other four countries is around average. In sub-domain 12 (Optical computing techniques), China's activity is well above average, while for the United Kingdom and, more significantly, for Germany it is below.

For Germany, we found an activity around average in almost all sub-domains. This is to be expected for a country with a large scientific production. The activity profile of a country is calculated in relation to the worldwide activity profile. Obviously, countries with a large publication output determine to a great extent the worldwide profile. Only in sub-domain 12 (Optical computing techniques), and even more clearly in 15 (Circuit design), the German activity was below world average.

In Figure 7-3, the activity profile of Germany is monitored for two periods: 1989/1990 and 1992/1993. This shows how German neural network researchers adjusted their scope during the period under study. The numerical values for Germany in 1989/1990 and 1992/1993 are presented with error bars. They were calculated under the assumption of a Poisson-distribution in order to have a first, but reasonable approximation of the statistics[11]. Only if the two data points of a sub-domain have no overlap in error range, they are considered significant.

[11] See also Engelsman and Van Raan (1990) A standard error for the absolute number of publications for Germany in both years was calculated by a relatively simple approximation: the square root of *n*, divided by *n*; *n* is the number of publications by Germany in a sub-domain. For the two extremes the activity index was determined and added to the figure.



Sub-domains			
1	NN-general	10	Signal Processing/Information Theory
2	Non-linear Systems	11	Self-adjusting Systems
3	Control Engineering	12	Optical Computing Techniques
4	Biology & Medicine	13	Parallel Architecture/Geophysics
5	NN devices	14	Probability & Statistics
6	Optical NN	15	Circuit Design
7	Expert Systems	16	Instrumentation
8	Optimisation	17	Character recognition
9	Robotics	18	Vision

Figure 7-3 Neural network research profile for Germany in 1989/1990 and 1992/1993

The figure shows striking changes in German activity characteristics. Particularly in sub-domain 16 (Instrumentation), the activity increased from below to above average. In absolute numbers the German activity increased from 3 to 21 publications, while the overall activity in this sub-domain increases from 90 to 353. As a result, we found that the Germany activity in this sub-domain has caught up with the overall (worldwide) trend. In sub-domain 15 (Circuit design), the trend was in the reversed direction. The worldwide declining activity in this sub-domain (see Figure 7-1), was also observed in the German activity (from 20 to 8 publications). We observe an increase of German activity in 8 (Optimisation), again similar to the overall trend of increasing activity. Finally, the unchanged low German activity in 12 (Optical computing techniques) is in contrast with the strikingly high Chinese activity in this sub-domain.

Optimisation

As an example of a more detailed actor-activity analysis, we 'zoomed' into sub-domain 8 (Optimisation). The map is constructed on the basis of co-occurrences of the most important (frequent) keywords (descriptors, controlled terms) in the publications belonging to this sub-domain in 1992/1993. For details, we refer to our foregoing paper Noyons and Van Raan (1998). The keywords were plotted into two dimensions by multidimensional scaling (MDS). Within these two dimensions, MDS yields a position for each mapped word, taking into account all relations (number of co-occurrences) this word has with all other words, as well as all relations the other words have with each other. The lines indicate relations between two individual words with a strong pair-wise relation (Salton index > 0.3).

Furthermore, we added 'map-external' information about the words which was not covered by the co-occurrence structure (that is, the position of the words in the map). Three kinds of information were added:

- *Central* topics in the sub-domain (words occurring in more than 10% of the publications) are printed in uppercase and bold face;
- Topics that show a *growing* interest of researchers in 1992/1993 compared with 1989/1990 (that is, the proportion of publications on the topic increased by more than 2%) appear with a '(+)' in the map, and topics showing a *decreasing* interest (of 2% or more) appear with a '(-)';
- Topics for which we found *no German activity* (no German publications) are underlined.

Looking for general trends in the sub-domain 'optimisation', we find two patterns on the map: the central/left side covering topics with a stable or decreasing interest, and the right/upper side covering topics with an increasing interest. It appears that more recent mathematical techniques (fuzzy logic, genetic algorithms) took over the leading position of older techniques (combinatorial mathematics). It should also be noted that some of the trends are in fact 'artificial' because the 'jargon' of the indexed terms was extended. For instance, the topic 'Neural Net' in the center of the map did not, of course, really become less interesting, but this term has been 'replaced' to a substantial extent by other, more specific terms (such as Hopfield NN, Recurrent NN).

Germany was active in almost all topics in this sub-domain. Still, there are four topics with an increasing worldwide interest, all in the same area (central right-hand side) of the map, for which no German activity was found: control system synthesis, non-linear control systems, machine control, and power system stability.

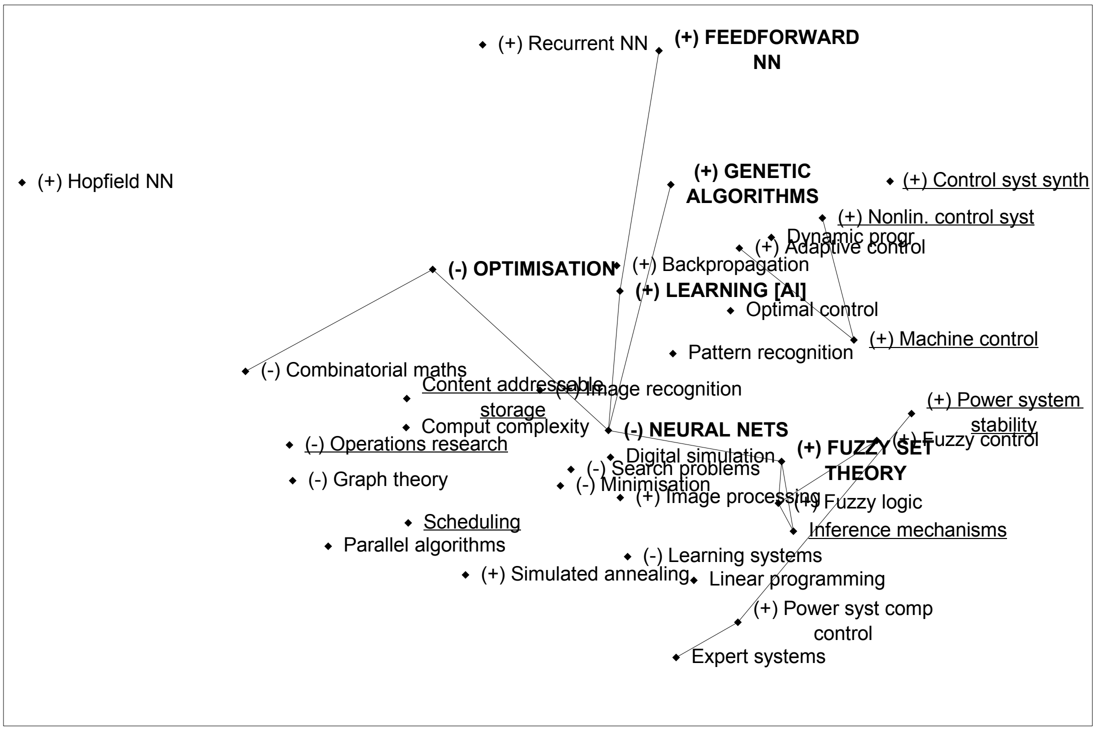


Figure 7-4 Fine structure map of sub-domain 8 (Optimisation) in 1992/1993

German actors' frequency of publication

In Table 7–3, the most frequently publishing German actors (with more than 2%) are listed by sub-domain. The number of publications in 1992/1993 are given, and their share related to all German publications in that particular sub-domain.

Table 7–3 Most important German actors by sub-domain in neural network research (1992/1992)

Subd.	*German actor*	*Publs in 92/93*	*% Actor-Germany*
1	TECH-UNIV-MUNICH, MUNICH	33	8.07
1	SIEMENS-AG, MUNICH	25	6.11
1	TECH-UNIV-DARMSTADT, DARMSTADT	21	5.13
1	DORTMUND-UNIV, DORTMUND	17	4.16
1	ERLANGEN-NURNBERG-UNIV, ERLANGEN	17	4.16
1	GER-NAT-RES-CTR-COMP-SCI, ST-AUGUSTIN	16	3.91
1	RUHR-UNIV-BOCHUM, BOCHUM	16	3.91
1	STUTTGART-UNIV, STUTTGART	14	3.42
1	GOTTINGEN-UNIV, GOTTINGEN	13	3.18

Subd.	*German actor*	*Publs in 92/93*	*% Actor-Germany*
1	WURZBURG-UNIV, WURZBURG	13	3.18
1	KARLSRUHE-UNIV, KARLSRUHE	12	2.93
1	PADERBORN-UNIV, PADERBORN	12	2.93
2	GOTTINGEN-UNIV, GOTTINGEN	4	8.51
2	TECH-UNIV-MUNICH, MUNICH	4	8.51
2	TECH-UNIV-DARMSTADT, DARMSTADT	3	6.38
3	SIEMENS-AG, MUNICH	6	11.54
3	DORTMUND-UNIV, DORTMUND	4	7.69
3	TECH-UNIV-DARMSTADT, DARMSTADT	4	7.69
4	TECH-UNIV-MUNICH, MUNICH	10	15.87
4	BIELEFELD-UNIV, BIELEFELD	5	7.94
4	PADERBORN-UNIV, PADERBORN	4	6.35
4	RUHR-UNIV-BOCHUM, BOCHUM	4	6.35
4	MAX-PLANCK-INST-BIOL-CYBERN, TUBINGEN	3	4.76
4	SIEMENS-AG, MUNICH	3	4.76
4	TECH-UNIV-BERLIN, BERLIN	3	4.76
5	TECH-UNIV-MUNICH, MUNICH	10	21.74
5	SIEMENS-AG, MUNICH	7	15.22
5	ERLANGEN-NURNBERG-UNIV, ERLANGEN	3	6.52
5	INST-MICROELECTRON, STUTTGART	3	6.52
5	TECH-UNIV-BERLIN, BERLIN	3	6.52
6	TECH-UNIV-DARMSTADT, DARMSTADT	5	8.20
6	HEIDELBERG-UNIV, HEIDELBERG	4	6.56
6	LEIPZIG-UNIV, LEIPZIG	4	6.56
6	DUSSELDORF-UNIV, DUSSELDORF	3	4.92
6	PADERBORN-UNIV, PADERBORN	3	4.92
6	TECH-UNIV-MUNICH, MUNICH	3	4.92
6	WURZBURG-UNIV, WURZBURG	3	4.92
7	TECH-UNIV-DARMSTADT, DARMSTADT	6	12.50
7	DORTMUND-UNIV, DORTMUND	5	10.42
7	TECH-UNIV-MUNICH, MUNICH	4	8.33
7	GER-NAT-RES-CTR-COMP-SCI, ST-AUGUSTIN	3	6.25
7	INST-MICROELECTRON, STUTTGART	3	6.25
8	TECH-UNIV-MUNICH, MUNICH	8	14.29
8	DORTMUND-UNIV, DORTMUND	4	7.14
8	ERLANGEN-NURNBERG-UNIV, ERLANGEN	4	7.14
8	GER-NAT-RES-CTR-COMP-SCI, ST-AUGUSTIN	3	5.36
8	HEIDELBERG-UNIV, HEIDELBERG	3	5.36
8	KARLSRUHE-UNIV, KARLSRUHE	3	5.36
9	WUPPERTAL-UNIV, WUPPERTAL	4	8.89
9	BIELEFELD-UNIV, BIELEFELD	3	6.67
9	GERMAN-AEROSP-RES-ESTABL, OBERPFAFFENHOFEN	3	6.67
9	KARLSRUHE-UNIV, KARLSRUHE	3	6.67
9	SIEMENS-AG, MUNICH	3	6.67
9	STUTTGART-UNIV, STUTTGART	3	6.67

Subd.	*German actor*	*Publs in 92/93*	*% Actor-Germany*
9	TECH-UNIV-DARMSTADT, DARMSTADT	3	6.67
10	SIEMENS-AG, MUNICH	4	15.38
10	DAIMLER-BENZ-AG, STUTTGART	2	7.69
10	DUSSELDORF-UNIV, DUSSELDORF	2	7.69
10	ERLANGEN-NURNBERG-UNIV, ERLANGEN	2	7.69
10	FRANKFURT-UNIV, FRANKFURT	2	7.69
10	GERMAN-AEROSP-RES-ESTABL, OBERPFAFFENHOFEN	2	7.69
11	KARLSRUHE-UNIV, KARLSRUHE	5	13.89
11	FRANKFURT-UNIV, FRANKFURT	3	8.33
11	PADERBORN-UNIV, PADERBORN	3	8.33
11	STUTTGART-UNIV, STUTTGART	3	8.33
11	GER-NAT-RES-CTR-COMP-SCI, ST-AUGUSTIN	2	5.56
12	DUISBURG-UNIV, DUISBURG	3	18.75
12	ESSEN-UNIV, ESSEN	2	12.50
12	SIEGEN-UNIV, SIEGEN	2	12.50
12	STUTTGART-UNIV, STUTTGART	2	12.50
12	TECH-UNIV-BERLIN, BERLIN	2	12.50
12	TECH-UNIV-MUNICH, MUNICH	2	12.50
13	DORTMUND-UNIV, DORTMUND	3	13.64
13	SIEMENS-AG, MUNICH	3	13.64
13	PADERBORN-UNIV, PADERBORN	2	9.09
13	TECH-UNIV-DARMSTADT, DARMSTADT	2	9.09
13	TECH-UNIV-MUNICH, MUNICH	2	9.09
14	SIEMENS-AG, MUNICH	4	18.18
14	ERLANGEN-NURNBERG-UNIV, ERLANGEN	3	13.64
15	DORTMUND-UNIV, DORTMUND	2	25.00
16	ERLANGEN-NURNBERG-UNIV, ERLANGEN	2	9.52
16	GER-NAT-RES-CTR-COMP-SCI, ST-AUGUSTIN	2	9.52
16	PADERBORN-UNIV, PADERBORN	2	9.52
17	KARLSRUHE-UNIV, KARLSRUHE	2	25.00
18	MARBURG-UNIV, MARBURG	2	15.38
18	PADERBORN-UNIV, PADERBORN	2	15.38
18	RUHR-UNIV-BOCHUM, BOCHUM	2	15.38

The Technical University of Munich can be found at the top of the list for nine sub-domains. Siemens AG appeared in eight lists, Paderborn University and the Technical University Darmstadt in seven lists. Moreover, for the central and most important sub-domain 1 (NN general) all these actors can be found near the top. As a result, we conclude that these are the most prominent actors, as far as neural network (engineering) research in Germany is concerned.

7.4 Concluding remarks and discussion

In this study, we have outlined an extensive procedure to evaluate the activity of a country, or an actor within a country, from the perspective of the international developments in a rather new and rapidly growing field like neural network research. The procedure is applied to the scientific output data of Germany in this field. The field is defined by, and therefore restricted to, publications covered by INSPEC, an international database on physics, electrical/electronic engineering and computer engineering.
We find that throughout the whole period 1989-1993, Germany is one of the leading countries in the field, with an activity around average in all sub-domains. In sub-domains with an increasing worldwide activity (NN-general; NN devices; optimisation; parallel architecture; and instrumentation), the share of German publications increased during the studied period. For circuit design we observe a significant decrease of German activity. But the worldwide activity in this sub-domain also decreases.

As an example, we also investigated the German activity in one specific sub-domain, optimisation, in more detail. This sub-domain shows an increasing worldwide interest from 1989 to 1993. In spite of this sharp increase, the German share of publication activity increases from below to somewhat above average. In the fine-structure map of this sub-domain, information about the evolution of topics, and about the German activity is integrated. In the map we observed a particular area with an increasing worldwide activity, in which, however, hardly any German activity was measured.

The most important German 'actors' in the field are the Technical University of Munich, Siemens AG, the Paderborn University, and the Technical University Darmstadt. They appear in the lists of achieving the most publications German organizations for one third to half of all 18 sub-domains. Moreover, they appear in the top-list of the central, and most important, sub-domain (NN general).

With the help of a combination of detailed mapping and actor analysis as described in this paper, we are able to disclose such detailed information. Moreover, by allowing the data itself to generate the structure of the field, we keep track of the evolving structure of science. For a rapidly developing field, like neural network research, this seems more appropriate than to force it into a structure based on aged notions and classifications. As a result, maps of science and technology offer a better evaluation tool than tables with numerical values only.

An important point of criticism of one of the two neural network experts consulted concerns time lags. According to this expert, our results, in particular for the fine-structure maps, will be influenced by the time lag of the classification scheme and the thesaurus of indexed words. Particularly in a new and rapidly developing field like neural network research, new, more specific, terms are introduced rather frequently.

To cope with this important problem, we are developing procedures to use abstract and title words to determine the structure of a research field. Once this is established, we will not depend on classification codes and indexed terms any more. As a result, the maps will come closer to the 'real world' of the researchers, because we will not have to wait for new terms and classifications to be included in the lists of database producers.

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8 Assessment of Flemish R&D in the field of Information Technology*

A bibliometric evaluation based on publication and patent data, combined with OECD research input statistics

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Assessment of Flemish R&D in the field of information technology

A bibliometric evaluation based on publication and patent data, combined with OECD research input statistics

Abstract

This paper outlines a method to evaluate a geographic region's performance in a research field. Using bibliometric indicators, an overview is given of Flemish R&D potential in information technology (IT). Flemish IT activity is presented within the context of recent international developments in this field. Both publication, patent data, and OECD input statistics are used in the study. We found that Flanders is quite productive in IT as far as publication activity is concerned. In contrast, the patenting productivity is rather low. Furthermore, the data indicate that Flemish R&D in IT has two strong points: image processing on the patent side, and processing technology on the publication side. Publications in the latter subdomain have an impact which is above world average.

8.1 Introduction

The study presented in this paper was performed for the Ministry for the Flemish Community. Flanders comprises the northern part of Belgium. The whole country used to be a centralized unitary state. To meet the demands for autonomy by both Flanders (Dutch-speaking) and Walonia (French-speaking), the unitary state was converted into a federation by constitutional amendments of 1971, 1980, and 1988. In 1988, the responsibility for education and nearly all competencies relating to science and technology policy were transferred to the regional authorities (Van den Berghe et al., 1998).

The results and details of the study are presented in Noyons et al. (1994). The main objective was to obtain an overview of the position of Flanders in the field of information technology (IT) by using bibliometric indicators. We merged and combined data from several sources in order to make the picture as complete as possible: (1) data from scientific publications as well as patent data are used to represent the output of IT activity; (2) the results for Flanders are analyzed in relation to the international developments in the field; (3) we normalized output data with input data by using OECD statistics[12]; and finally, (4) we calculated the impact of the Flemish publication output in IT and compared it to the world average. In addition to the comparison of Flemish output with worldwide output and impact standards, we included data from Belgium and three European countries in the study. These three

[12] The combination of input and output data is not new. Recent studies (Leydesdorff and Gauthier, 1996, Jacobsson et al., 1996, and Gomez et al., 1995) have shown the use of R&D input figures.

countries (the Netherlands, France, and Germany) are Belgium's neighbors and its most important trade partners. The study covers a period of 10 years (1983 to 1992).

8.2 Data and methods

8.2.1 Bibliographic databases and the delineation of the field

The output data used in this study was retrieved from two international bibliographic databases. The publication data was collected from INSPEC, a worldwide database on Physics, Electronics and Computing, in which all publication are classified with by means of the Physics Abstracts Classification Scheme (PACS). The patent data was extracted from the ESPACE-Bulletin database, a product from the European Patent Office (EPO), in which all published patents are enriched by one or more International Patent Classification (IPC) codes.

Table 8–1 21 subdomains in information technology

Code	*subdomain description*
01	Image Processing
02	Computer Aided Design
03	Computer Integrated Manufacturing & Production Control
04	Communication
05	Computer Architecture
06	Educational Systems
07	Encryption & Security
08	Geographical Information Systems
09	Graphical Information & Computer Graphics
10	Information Processing
11	Micro-electronics & General Electronic Techniques
12	Multi-media Techniques
13	Numerical Analysis & Applied Mathematics
14	Opto-electronics
15	Process Control
16	Peripherals
17	Sensors & Actuators
18	Signal Processing (Analogue, Digital)
19	Software Engineering
20	Language Technology
21	Processing Technology

The INSPEC database has four sections: physics; electrical and electronic engineering; computer technology; and IT. This database is considered to cover the field of IT in its broadest sense. The main types of publications included in this database are journal articles, book chapters, and proceeding papers. The European Patent database contains all patents published by the EPO since 1978. It covers patent data from all possible science and technology fields, including IT, as far as the products and processes are patentable. From both databases, items related to IT were selected and classified in 21 subdomains. These subdomains are listed in Table 8–1.

For the purpose of this study, the Flemish Institute for the Promotion of Scientific-Technological Research in Industry (IWT), which supports industrial R&D in Flanders, provided the description of these 21 subdomains. In an interactive process between IWT and CWTS, publications and patents were assigned to the subdomains[13]. A publication can be assigned to more than one subdomain.

Experts of the Ministry of the Flemish Community were able to assign each publication, on the basis of the address of the first author[14], and each patent, on the basis of the address of the applicant or inventor, either to Flanders or to the other part of Belgium.

Patents were primarily assigned to countries by using the inventors' addresses. It has been argued that the inventor's address is to be preferred over the applicant's when assessing a country's actual R&D activity (Schmoch and Kirsch, 1993).

8.2.2 Combining publication and patent data

An important issue in the study is the combination of publication and patent data. The idea was to generate a picture of Flemish IT which was as complete as possible. This does not mean that we considered a patent and a scientific publication as one of a kind: they do represent different 'worlds'. Still, one may assume some overlap between these two 'worlds'. In both cases, the intellectual properties are being protected. A patent provides financial protection and a publication provides intellectual protection. In most science and technology fields, and not in the least in IT, both aspects of research and development are of great importance: the market-oriented aspect, usually protected by patents, and the more fundamental (intellectual) one, usually protected by scientific publications. As an additional argument to combine both types of data, we note an observed tendency of both 'worlds' to mingle. It has been stated that companies dispense with a patent application and rather publish the result of a development (Grupp and Schmoch, 1992). Nevertheless, 'trends' may be discerned recently in academic organizations to increase their 'patent activity' in order to protect their knowledge in a commercially more interesting way. According to the data from the EPO (ESPACE Bulletin CD-ROM) in the past 10 years, the

[13] The available keywords per subdomain were translated by CWTS into classification codes of INSPEC (Physics Abstracts Classification Scheme codes) and EPO (International Patent Classification codes). Experts from IWT corrected the lists before they were used to select the publications and patents per subdomain.
[14] INSPEC includes the address of the first author only.

percentage of patents with an academic address in a patent description) has increased from around 0.9 to 1.25[15].

Finally, we should note the coverage of some of the subdomains by patents. In IT, a significant part concerns software engineering. However, software is not (yet) patentable as such. This is the main reason why no patent activity is found in some of the subdomains. For these particular subdomains in the study, only the publication output is used.

8.2.3 Bibliometric indicators

As outlined in section 1, the objective was to explore IT developments in general and to obtain the characteristics of the activity of Flanders and of three other European countries in this field. We characterized general developments in the field of IT by counting the publications in the 21 subdomains over the period 1983 to 1992. In addition, the total number of publications in IT worldwide, as well as the total number of publications in the field from Flanders, Belgium as a whole, and three other European countries were calculated.

The characteristics of Flemish IT research can be obtained by calculating activity indices. The activity index is derived from the Revealed Patent Advantage (RPA) indicator [see the work of Engelsman and van Raan (1993) for an extensive description of its history], which is an adjusted version of the Revealed Technology Advantage (RTA) indicator, described by Soete and Wyatt (1983). The index is calculated by the ratio of the number of publications (or patents) of a country in a particular subdomain, divided by the number of total publications in these subdomains, and the number of publications of that country in the whole field, divided by the total number of publications in the field. See Figure 8-1.

[15] In the applicant field of the patents we searched for addresses with strings like 'UNIV', 'ACAD'.

$$\ln\left(\frac{P_{ij} \Big/ \sum_{l} P_{il}}{\sum_{k} P_{kj} \Big/ \sum_{k}\sum_{l} P_{kl}}\right)$$

where:

P_{ij}	=	Number of publications/patents of country i in subdomain j
$\sum_{l} P_{il}$	=	Number of publications/patents of country i in the whole field
$\sum_{k} P_{kj}$	=	Number of publications/patents of all countries in subdomain j
$\sum_{k}\sum_{l} P_{kl}$	=	Number of publications/patents of all countries in the whole field
ln	=	Natural Logarithm

Figure 8-1 Activity Index formula

In each of the 21 subdomains, the activity index per country values between -1 and 1. The range of scores of a country renders its activity profile. Like in the work of Noyons and van Raan (1996), we calculated the standard error bars for each data point of Flanders. By comparing the profile of Flanders with those of the other countries in this study, we were able to view its activity from an international perspective. Moreover, by determining the activity profile of Flanders in two successive 5-year periods, changes in the activity profile during the studied period can be examined.

Furthermore, the overall publication and patenting output of Flanders, Belgium as a whole, and of the three other countries was normalized using several input indicators. These input indicators included the country's population, the gross national (regional) product, and the country's R&D expenditures in the categories of 'higher education and government' (for publications) and 'business and private, non-profit' (for patents), respectively. This data was extracted from the 'OECD - Main Science and Technology Indicators'. For Flanders they were extracted from a database with regional indicators at the Ministry of the Flemish Community. The results provide an indication of the scientific productivity of Flanders and of the studied countries, taking into account the available financial and human resources.

Finally, an advanced citation analysis was performed on the publication output of Flanders during the years 1983 to 1992 in order to assess the impact. This was accomplished by collecting citations received by the publications selected from

INSPEC from publications in journals covered by the Science Citation Index. Details about this methodology are presented in De Bruin et al. (1993).

8.3 Results

In this section, we will discuss the results of the bibliometric evaluation of Flemish IT. The discussion highlights two major points: an exploration of overall developments in IT, and the position of Flemish R&D in this field.

8.3.1 Exploration of the developments in IT

The objective of this section is to present an overview of the main developments in the field from a worldwide perspective. This overview is generated by calculating the average increase or decrease of numbers of publications per subdomain in IT, as represented by publications and patents selected by PACS codes and IPC codes. Per subdomain, a growth index is calculated by the average of relative differences between two successive years during the entire period (1983 to 1992). A relative difference is calculated by dividing the absolute difference between year *t* and year *t+1* by the numbers of publications/patents in year *t*. The results for the publications and the patents are given in Figure 8-2.

The figure shows that there was a significant increase of publication activity in subdomains 07 (Encryption & Security) and 08 (Geographical Information Systems). Unfortunately, technological developments in these subdomains are not patentable, so no comparison can be made with technological developments. In subdomain 16 (Peripherals), we find a decrease in publication activity (particularly in the second part of the studied period), whereas on the patent side, we observe an increased activity. These contrasting trends may be caused by the fact that basic research in this subdomain has reached a certain saturation point, but product R&D, as represented by patents, is still growing. For all other subdomains, an average increase of activity is observed between 0 and 1, which is similar to the growth of the number of publications included in INSPEC during this period. One of the IT scientists who was interviewed to discuss the results of the study, expressed his concern about the use of classification codes to characterize the field. He properly suggested that INSPEC or EPO may have introduced new classification codes at some point during the studied period. A strong activity increase in some of the subdomains may then be a result of the introduction of a new classification code in the scheme, rather than an increase of R&D. We actually observed that new classification codes have been introduced in some of the subdomains with a strongly increasing activity. It is even quite common in new or rapidly developing fields such as IT [see the works of McCain and Whitney (1994), Noyons and Van Raan (1996), and Lawson et al. (1980)]. We argue, however, that this 'artifact' is not strange to the actual developments in the field. The introduction of a new classification code indicates a significant development in that area. As long as we take the most recent scheme as starting point, we will cover such developments. If we would start with a scheme used at the beginning of the period under consideration, we would in fact disregard recent developments in the field. Moreover, publications entered in the database in the most recent years would be left out of the analyses because mainly new classification codes may be assigned to them[16].

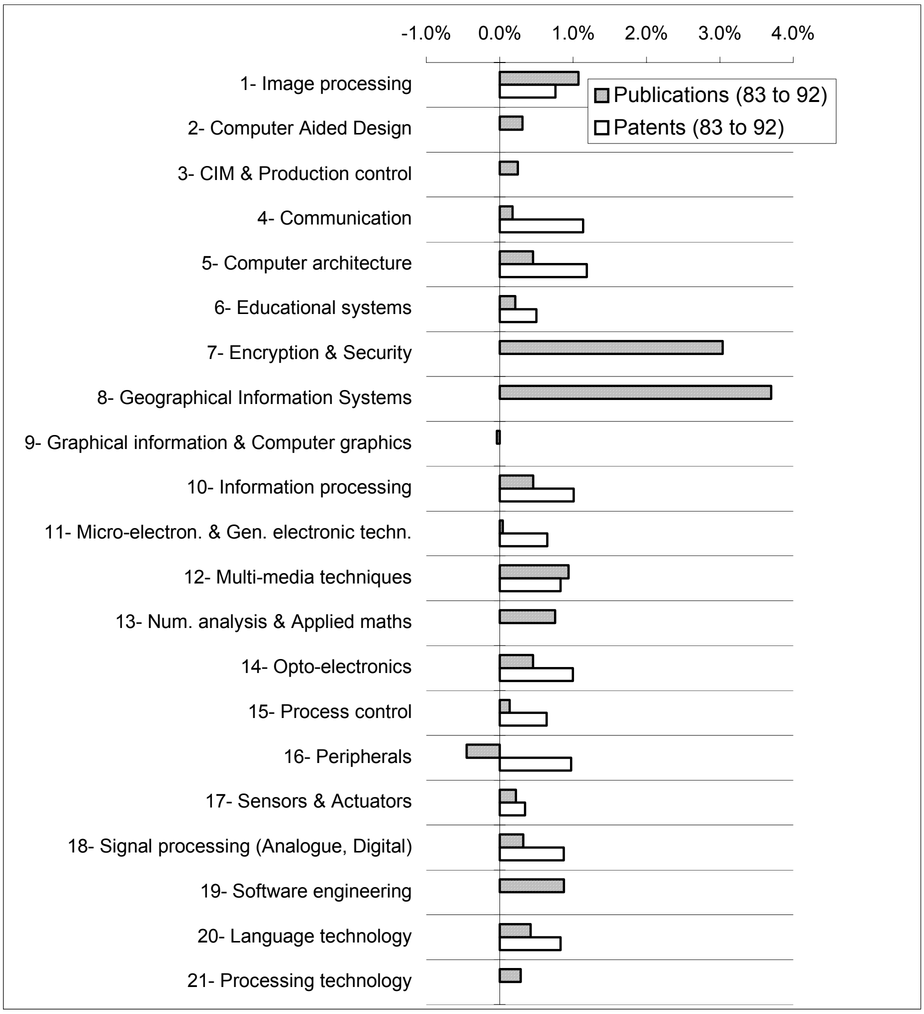

Figure 8-2 Average growth of the number of IT publications/patents from year to year during 1983 to 1992

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[16] This viewpoint is extensively discussed in Noyons and Van Raan (1998).

8.3.2 Flemish activity in IT

The identified trends in the different subdomains are used to put the results for Flanders in a wider perspective. In Table 8–2, the numbers of publications and patents per year are given for Flanders, Belgium as a whole, the Netherlands, France, and Germany. The numbers for Flanders are broken down over the subdomains in Table 8–3.

Table 8–2 Numbers of publications (a) and patents (b) in IT in 1983-1992

a Publications

	1983	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*
Flanders	238	273	258	291	358	424	476	590	555	582
Belgium	429	433	452	495	579	670	726	885	839	937
Netherlands	823	946	888	1149	1205	1368	1593	1744	1950	1857
France	2031	2279	2660	3113	3466	3626	4121	4453	4437	4827
Germany	4563	4821	4882	5471	5574	6201	6039	7091	7047	6321

b Patents

	1983	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*
Flanders	16	20	25	25	38	43	35	48	71	67
Belgium	38	43	43	43	71	68	61	75	105	97
Netherlands	220	257	266	307	345	356	449	442	415	406
France	665	695	703	828	912	926	1053	1096	1237	1216
Germany	1119	1275	1431	1666	1749	1951	2005	2173	2192	2175

A characterization of Flemish activity is obtained by calculating the activity index per subdomain. The profile of scores reflects the focus of Flemish research activity in IT. This Flemish IT activity profile is compared with that of Belgium and three other European countries (Netherlands, Germany, and France). The results are presented in Figure 8-3 (publications) and Figure 8-4 (patents).

Table 8–3 Numbers of Flemish publications (a) and patents (b) in 21 IT subdomains

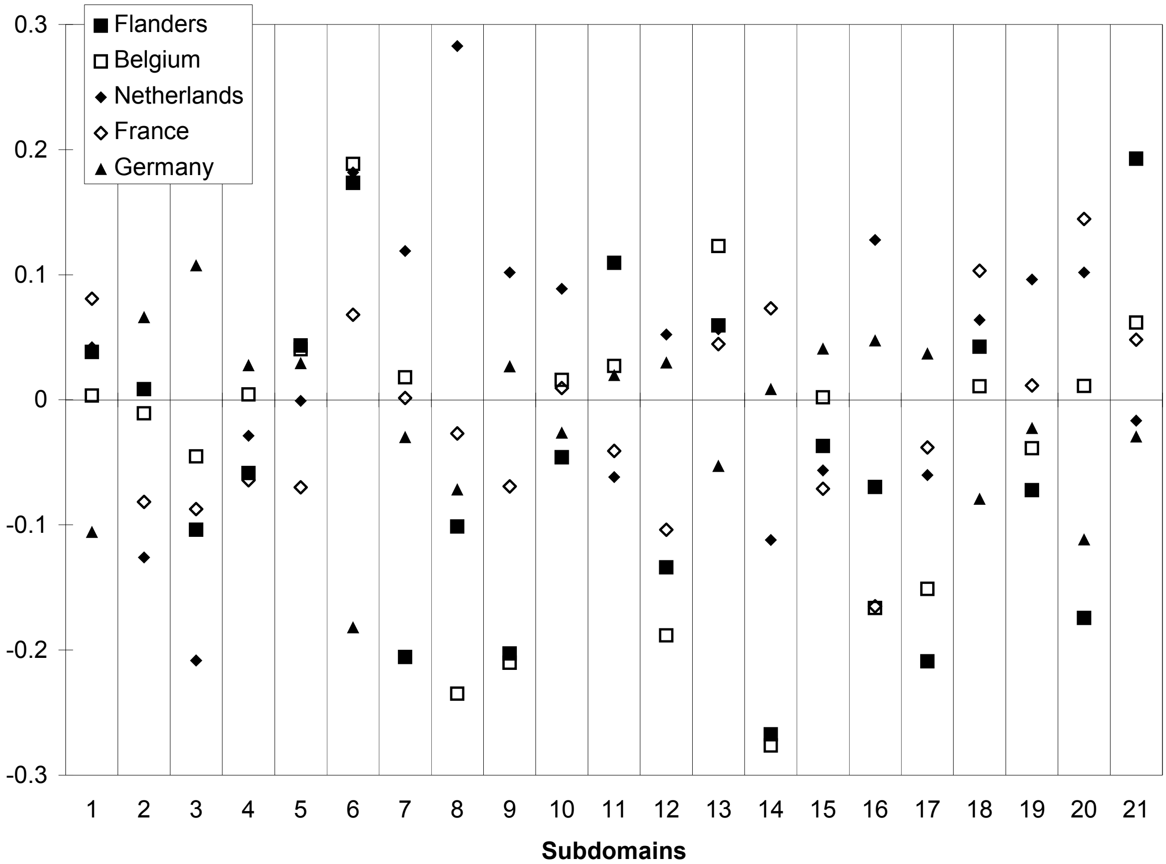
a Publications

Sub	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*
01	20	17	19	17	28	35	34	53	42	39
02	36	29	37	35	54	58	88	91	63	74
03	12	14	9	10	23	24	16	34	16	23
04	34	47	35	35	64	55	45	90	59	73
05	11	15	14	30	34	45	52	56	59	58
06	2	5	4	6	3	14	6	9	9	6
07	0	0	0	0	0	0	0	1	2	2
08	0	1	0	0	0	0	0	1	1	4
09	0	0	1	2	1	4	4	8	5	11
10	29	31	33	53	59	73	93	121	97	106
11	54	37	49	49	50	59	82	97	79	92
12	0	1	0	2	1	1	10	11	3	6
13	43	72	46	60	65	86	86	106	127	125
14	12	14	16	11	11	16	22	31	46	39
15	22	30	19	32	36	35	45	43	34	43
16	3	7	4	5	7	12	12	10	14	8
17	23	29	27	24	29	16	36	45	38	36
18	23	36	36	30	41	55	55	70	62	50
19	2	7	6	15	22	37	33	36	46	61
20	3	3	1	8	2	9	13	7	9	8
21	43	50	60	60	82	98	122	143	179	152

b Patents

Sub	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*
01	7	4	2	10	11	17	17	14	20	27
02										
03										
04	4	5	13	6	14	17	7	18	31	19
05	0	0	1	3	3	1	1	3	4	6
06	0	0	0	0	0	0	0	0	0	0
07										
08										
09										
10	0	0	1	0	0	0	0	0	1	0
11	6	6	7	6	5	3	6	4	12	7
12	0	0	0	1	0	0	1	1	1	1
13										
14	0	3	4	3	3	4	5	7	5	3
15	0	0	0	1	0	1	2	1	0	0
16	1	2	0	1	4	1	0	4	3	7
17	0	1	0	0	1	2	0	0	0	0
18	0	0	2	0	1	0	0	0	0	1
19										
20	0	0	0	0	0	0	0	0	0	0
21										

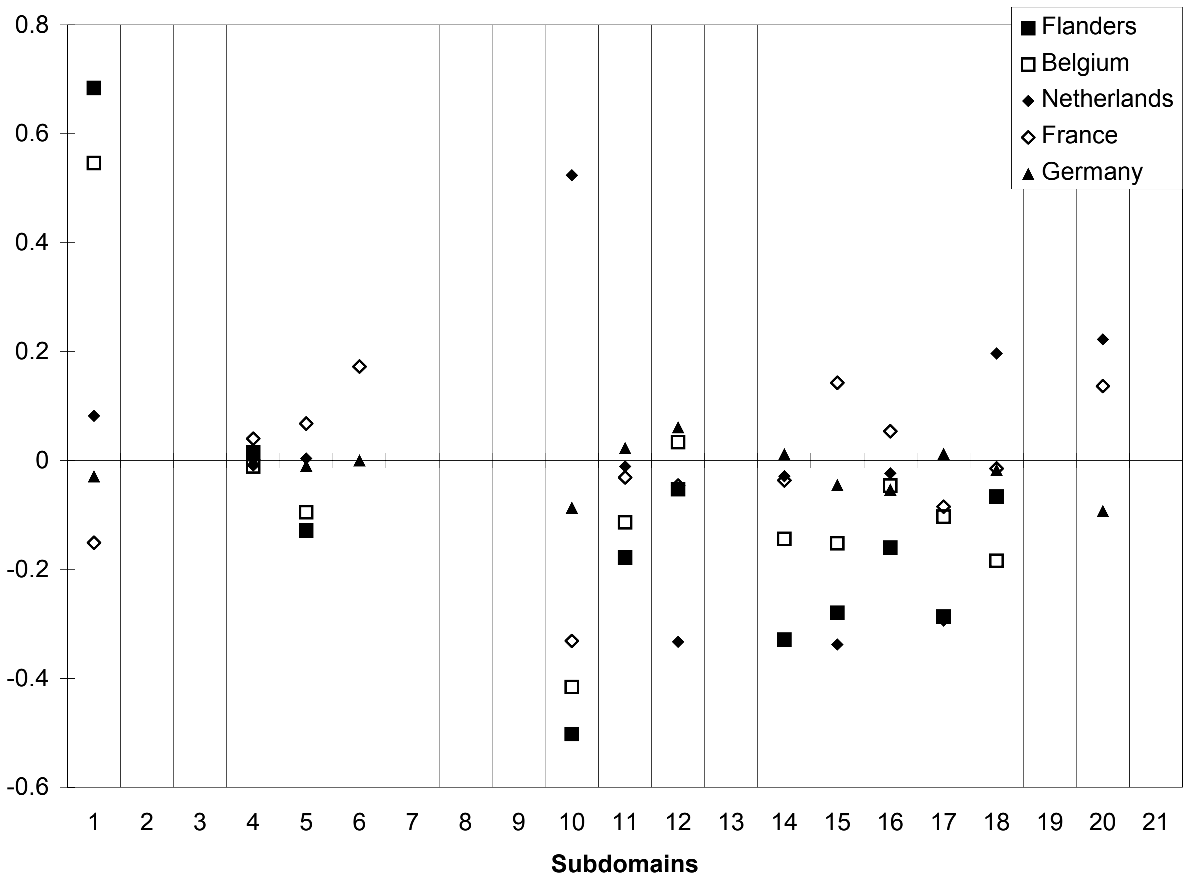
For subdomain names: see Table 1 or Figure 2



Subdomains:

01	Image Processing	11	Micro-electron. & General Electronic Techniques
02	Computer Aided Design	12	Multimedia Techniques
03	CIM & Production Control	13	Numerical Analysis & Applied Mathematics
04	Communication	14	Opto-electronics
05	Computer Architecture	15	Process Control
06	Educational Systems	16	Peripherals
07	Encryption & Security	17	Sensors & Actuators
08	Geographical Information Systems	18	Signal Processing (Analogue, Digital)
09	Graphical Information & Computer Graphics	19	Software Engineering
10	Information Processing	20	Language Technology
		21	Processing Technology

Figure 8-3 Activity index for the publication output of Flanders and of 4 European Countries in all IT subdomains in the period 1983-1992



Subdomains:

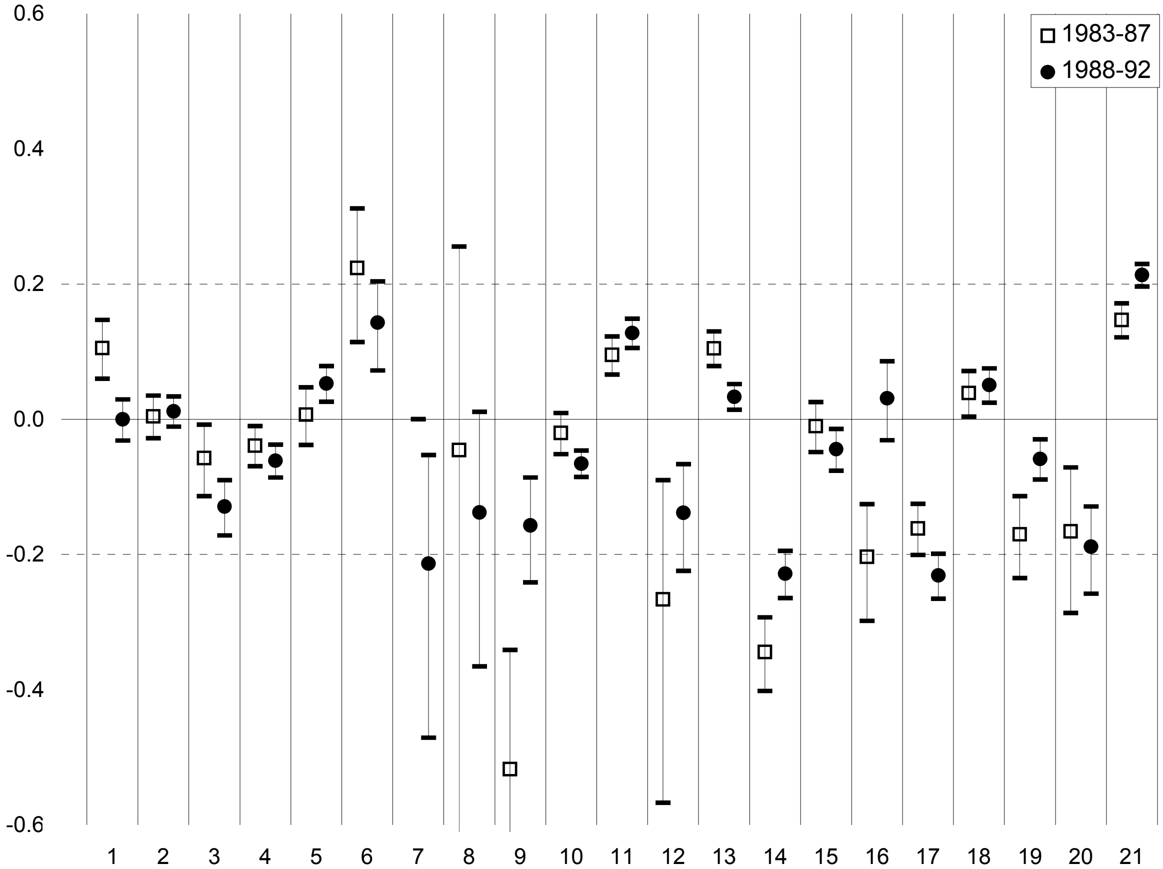
01	Image Processing	11	Micro-electron. & General Electronic Techniques
02	Computer Aided Design	12	Multimedia Techniques
03	CIM & Production Control	13	Numerical Analysis & Applied Mathematics
04	Communication	14	Opto-electronics
05	Computer Architecture	15	Process Control
06	Educational Systems	16	Peripherals
07	Encryption & Security	17	Sensors & Actuators
08	Geographical Information Systems	18	Signal Processing (Analogue, Digital)
09	Graphical Information & Computer Graphics	19	Software Engineering
10	Information Processing	20	Language Technology
		21	Processing Technology

Figure 8-4 Activity index for the patenting output of Flanders and of 4 European Countries in all IT subdomains in the period 1983-1992

For reasons of clarity, we did not include error bars in the figure. That would cause the whole figure to become too 'crowded'. Instead, we calculated the average error of the publication activity index (0.004) and for the patent activity index (0.026).

In Figure 8-3, a clear Flemish preference for subdomain 21 (Processing technology) is visible. Also a preference for 06 (Educational systems) is observed. Furthermore, the chart shows a low Flemish interest for 07 (Encryption & Security), 09 (Graphical information & Computer graphics), 14 (Opto-electronics), 17 (Sensors & Actuators), and 20 (Language Technology). The profile of Belgium as a whole is quite similar to that of Flanders. Some of the seemingly large differences (07 and 08) are not statistically significant due to the low number of publications involved. In two other subdomains (20: Language technology and 21: Processing technology) the differences are significant. In language technology, Belgium's overall activity is much higher than in Flanders, and in processing technology it is the other way around. In general, we can observe a clear-cut profile of Flemish IT. In many subdomains, it has either the lowest or the highest activity index. We observe a similar clear-cut activity profile for the Netherlands, albeit with different focuses.

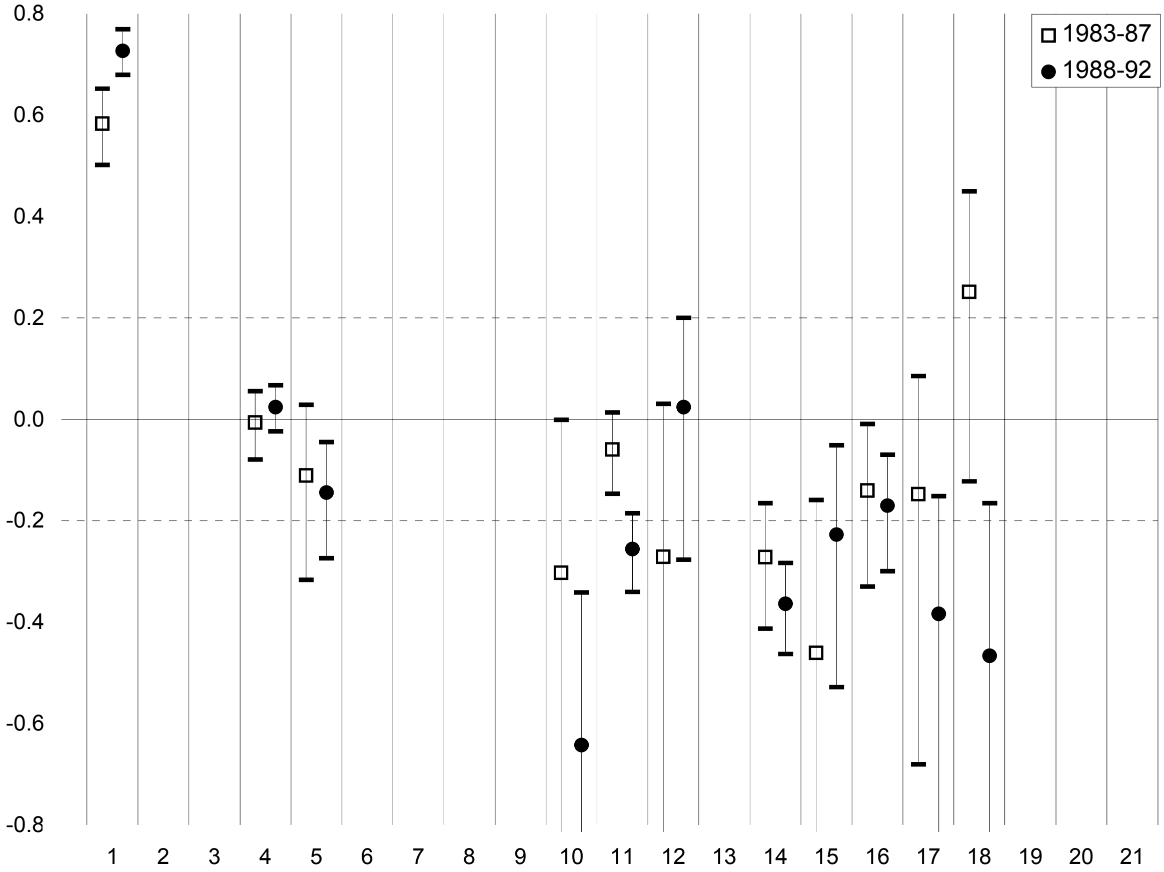
On the patent side (Figure 8-4), we should interpret the results with great care. Firstly, because there are some subdomains for which no patent data is available: 02: Computer Aided Design, 03: CIM & Production Control, 07: Encryption & Security, 08: Geographical Information Systems, 09: Graphical Information & Computer Graphics, 13: Numerical Analysis & Applied Mathematics, 19: Software Engineering, and 21: Processing Technology. The reason for this is primarily that R&D in these subdomains mainly concerns software development which is more difficult to be patented as such under the European patent law. Subdomain 21 was added to the list of subdomains at a later stage in the study without patent data. Furthermore, in two other subdomains, Flanders has no patent activity at all (6: Educational Systems and 20: Language Technology). In these two subdomains, the patent activity index cannot be calculated. In subdomains 10 (Information Processing), 15 (Process Control) and 16 (Peripherals), the Flemish activity index is calculated as being low, but this is not significant (i.e., the absolute number of patents is too small). In subdomain 14 (Opto-electronics), the low activity index is significant. The number of patents in this subdomain is 37 over the whole period, which is less than the average activity of Flanders in the whole field. Among all of the subdomains, the highest activity index for Flanders is measured in subdomain 01 (Image Processing). We conclude that the activity on the patent side of the Flemish IT focuses clearly on this particular subdomain.



Subdomains:

01	Image Processing	11	Micro-electron. & General Electronic Techniques
02	Computer Aided Design	12	Multimedia Techniques
03	CIM & Production Control	13	Numerical Analysis & Applied Mathematics
04	Communication	14	Opto-electronics
05	Computer Architecture	15	Process Control
06	Educational Systems	16	Peripherals
07	Encryption & Security	17	Sensors & Actuators
08	Geographical Information Systems	18	Signal Processing (Analogue, Digital)
09	Graphical Information & Computer Graphics	19	Software Engineering
10	Information Processing	20	Language Technology
		21	Processing Technology

Figure 8-5 Activity index for publication output of Flanders in 1983-1987 and 1988-1992



Subdomains:

01	Image Processing	11	Micro-electron. & General Electronic Techniques
02	Computer Aided Design	12	Multimedia Techniques
03	CIM & Production Control	13	Numerical Analysis & Applied Mathematics
04	Communication	14	Opto-electronics
05	Computer Architecture	15	Process Control
06	Educational Systems	16	Peripherals
07	Encryption & Security	17	Sensors & Actuators
08	Geographical Information Systems	18	Signal Processing (Analogue, Digital)
09	Graphical Information & Computer Graphics	19	Software Engineering
10	Information Processing	20	Language Technology
		21	Processing Technology

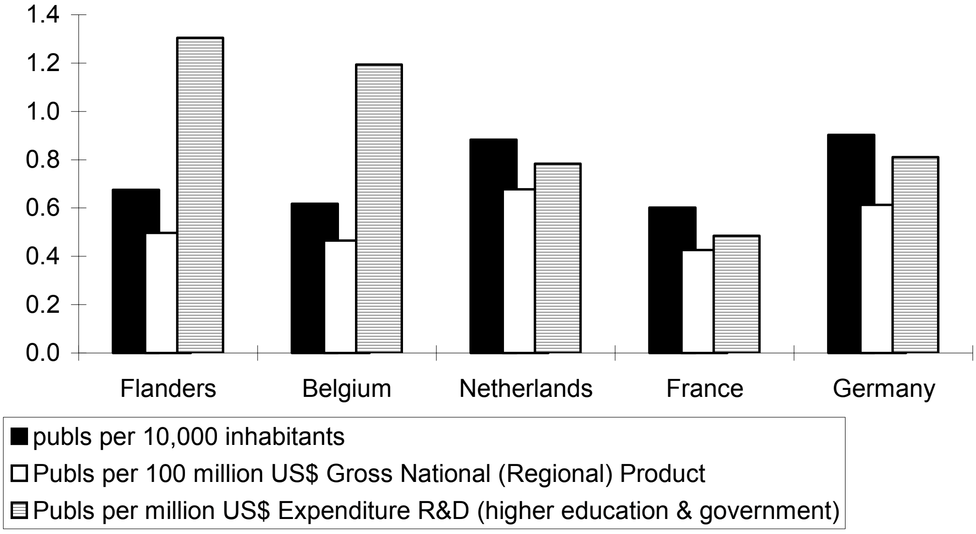
Figure 8-6 Activity index for patenting output of Flanders in 1983-1987 and 1988-1992

To analyze the time evolution, the Flemish activity index, calculated for the first five-year period and for the second 5-year period, is plotted in Figure 8-5 and Figure 8-6. In Figure 8-5, there is a general trend visible. In 11 of the 21 subdomains, the activity index approaches the average during the studied period. In Figure 8-3, we observed that countries with a larger output tend to have an index (in all subdomains) around this average, whereas 'smaller' countries seem to have more outliers. It seems that Flanders changed its IT publication strategy in a direction similar to European countries with a large output. A particular exception to this trend is 21 (Processing Technology). In this subdomain, the number of publications have been doubled to 694, resulting in an activity index over 0.2. It is becoming more and more a spearhead of Flemish IT. On the patent side (Figure 8-6), we observe a similar pattern. The subdomain of Image Processing has become even more important in the last 5 years than it already was in the first five. Activity in subdomain 04 (Communication) remains around average. In all other subdomains, changes are hardly significant, as the numbers of patents applied for by Flanders are low.

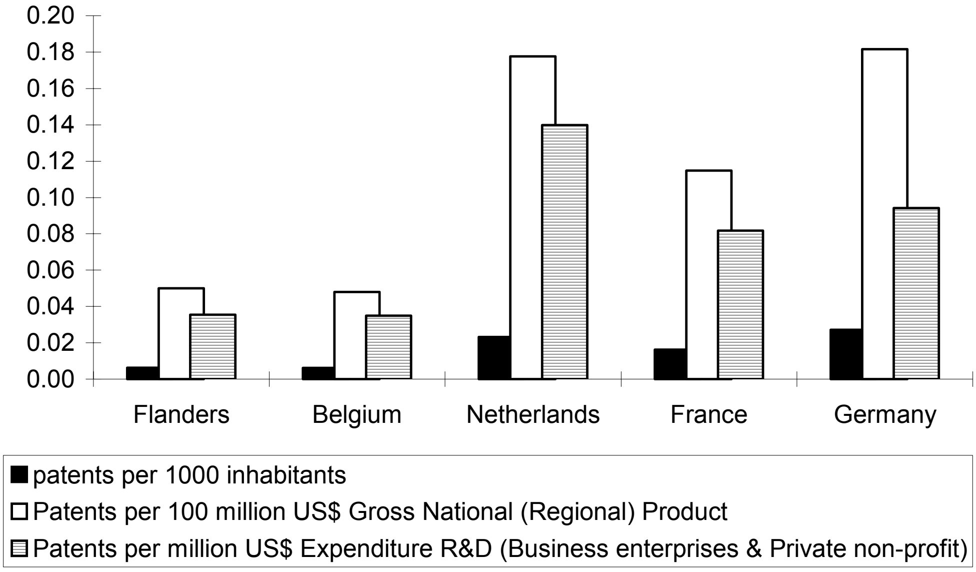
For the overall Flemish IT activity, we may conclude that it seems to focus more and more on two subdomains, Image Processing on the patent side, and Processing Technology on the publication side.

8.3.3 Productivity of Flemish IT

An estimation of the productivity in IT is made by normalizing the output with several input indicators. From the 'OECD - Main Science and Technology Indicators', the input data was obtained for the studied countries (Belgium, France, Germany, and the Netherlands). For Flanders, the data was extracted from the database with regional indicators at the Ministry of the Flemish Community. Both publication and patent data were normalized to the number of inhabitants, the Gross National (Regional) Product, and relevant data on R&D expenditures. The results are presented in Figure 8-7. Most striking in these charts is the observation that on the average, Flanders (and Belgium) perform similarly compared to the other European countries as far as publication output is concerned. On the patent side, however, the productivity is far below that of the other countries. The publication productivity becomes even better in Flanders and Belgium than in three other European countries, when normalized to R&D expenditures in 'higher education and government'. An additional striking observation about Flanders (Belgium) in relation to the other countries, concerns the productivity normalized to the aimed R&D expenditure on the one hand, and productivity normalized to the Gross National Product (GNP) on the other hand. In the other countries, both indicators are at a similar level. In Flanders and Belgium however, the productivity normalized to the aimed R&D expenditure is significantly higher. As the activity (publication output) remains the same, this difference confirms the fact that public R&D expenditures, mainly concentrated in universities and public research institutions, as part of GNP is considerably lower in Flanders and Belgium during the studied period than in the other countries.



(a) Publications



(b) Patents

Figure 8-7 Average productivity measured with three input variables in IT (1983-1992)

8.3.4 Impact of Flemish IT publication output

Finally, we assessed the impact or 'visibility' of Flemish IT publications. The impact is measured by counting citations to these publications and by comparing it with world averages. First we make some remarks about the data. The publications subject to the citation analyses are only those which are covered by the Science Citation Index (SCI). The output analyses in the previous sections were based on data derived from the INSPEC database. The citation-analyzed set of Flemish IT publications, therefore, is a subset of the total Flemish INSPEC output in IT. The applied analyses are described in detail in the work of De Bruin et al. (1993). An overview of the figures for the Flemish IT publication output is given in Table 8–4.

Table 8–4 Bibliometric scores of Flemish IT publications (1983-1991)

Indicator	*Description*	*Score*
P	Number of IT publications in SCI	992
P/Inspec	Percentage of total Flemish IT output covered in SCI citation analysis	28.65
C	Total number of received citations	5,682
CPP	Average number of citations per publication	5.7
CPPex	CPP excluding self-citations	4.1
Self-Cits	Percentage of self-citations	28.5
JCSm	Average journal impact factor	6.9
FCSm	World citation average in IT	5.6
CPP/JCSm	Citation average/journal impact factor	0.8
CPP/FCSm	Citation average/world citation average in IT	1.0
JCSm/FCSm	Journal impact factor/world citation average in IT	1.2

The results in Table 8–4 show that overall Flemish IT performs well: a total of 992 Flemish publications (*P*) in the sector of IT was cited 5,682 times until 1995 (*C*). The average of 5.7 citations per publication (CPP) decreases to 4 (CPPex) if self-citations are excluded. The average number of citations per IT publication is normalized by the citation average of the journal set used by Flemish IT researchers (CPP/JCSm), and by the world average in the subfields (CPP/FCSm, where the subfields are defined through ISI journal categories) in which they are active. The most important ISI categories in our database are: Electrical Engineering, Applied Physics, and Applied Mathematics. The Flemish IT impact is around the world average (CPP/FCSm = 5.6). CPP/JCSm is somewhat lower than the CPP/FCSm because their JCSm is above their FCSm. This means that the Flemish IT researchers publish their work in journals with an impact factor which is above the world average in the field.

In Table 8–5, the data has been broken down over the subdomains. The results show that there are significant differences with respect to numbers of papers included in the citation analysis and with respect to the coverage of numbers included in the citation analysis (SCI) as related to the number included in the production analysis (INSPEC). The covered percentages (*P*/Inspec) range from almost nothing to more than 50.

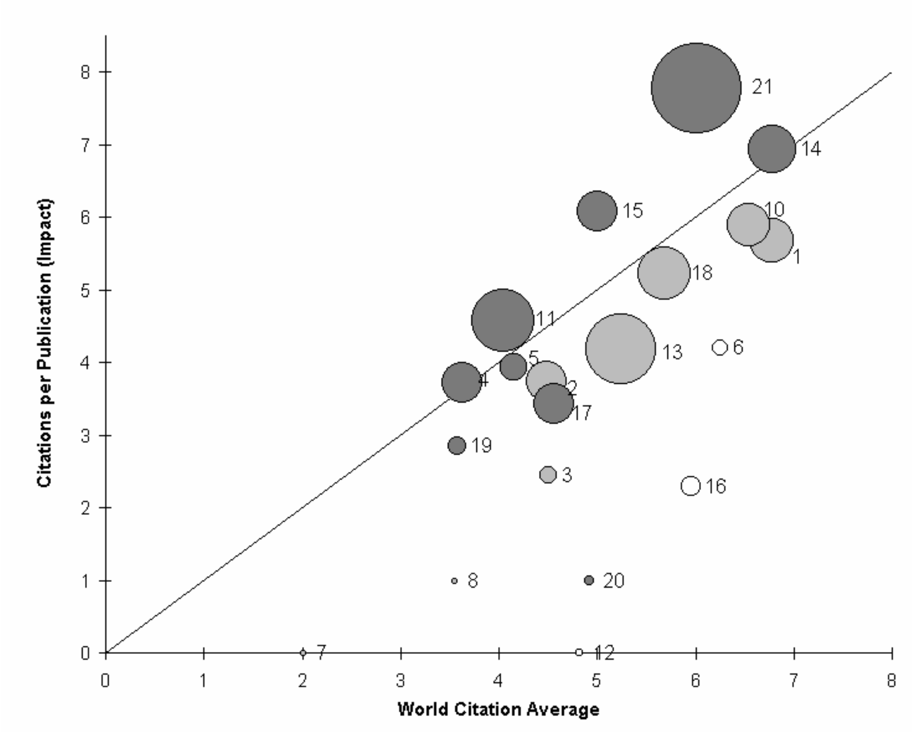
Table 8–5 Bibliometric scores of Flemish IT publications by subdomain (1983-1991)

sub	*P*	*P/ Inspec*	*C*	*CPP*	*CPP ex*	*JCSm*	*FCSm*	*CPP/ JCSm*	*CPP/ FCSm*	*JCSm/ FCSm*	*% Self Cits*
01	84	30.6	477	5.7	4.3	5.8	6.8	1.0	0.8	0.9	24
02	67	13.6	251	3.8	2.4	4.5	4.5	0.8	0.8	1.0	36
03	11	5.1	27	2.5	1.6	4.4	4.5	0.6	0.5	1.0	37
04	71	15.3	265	3.7	2.9	5.8	3.6	0.6	1.0	1.6	23
05	34	10.8	134	3.9	3.0	5.0	4.2	0.8	1.0	1.2	23
06	10	15.5	42	4.2	3.2	2.1	6.3	2.0	0.7	0.3	24
07	1	33.3		0		1.7	2.0	0	0	0.9	
08	1	33.3	1	1.0	1.0	3.2	3.5	0.3	0.3	0.9	0
09	1	4.0		0			13.0				
10	81	13.6	478	5.9	3.9	7.2	6.5	0.8	0.9	1.1	34
11	172	30.8	789	4.6	3.4	5.3	4.0	0.9	1.1	1.3	27
12	2	3.4		0		2.4	4.8			0.5	
13	225	31.8	943	4.2	2.9	6.1	5.2	0.7	0.8	1.2	31
14	100	52.5	694	6.9	5.1	9.1	6.8	0.8	1.0	1.3	27
15	69	23.0	420	6.1	4.2	6.9	5.0	0.9	1.2	1.4	31
16	17	23.0	39	2.3	1.1	4.8	6.0	0.5	0.4	0.8	54
17	67	22.5	230	3.4	2.5	5.9	4.6	0.6	0.8	1.3	28
18	121	27.9	634	5.2	3.4	5.1	5.7	1.0	0.9	0.9	36
19	14	6.9	40	2.9	1.8	4.3	3.6	0.7	0.8	1.2	38
20	3	5.5	3	1.0	0	7.0	4.9	0.1	0.2	1.4	100
21	357	41.7	2781	7.8	5.8	8.0	6.0	1.0	1.3	1.3	26

Subdomains:

01	Image Processing	11	Micro-electron. & General Electronic Techniques
02	Computer Aided Design	12	Multimedia Techniques
03	CIM & Production Control	13	Numerical Analysis & Applied Mathematics
04	Communication	14	Opto-electronics
05	Computer Architecture	15	Process Control
06	Educational Systems	16	Peripherals
07	Encryption & Security	17	Sensors & Actuators
08	Geographical Information Systems	18	Signal Processing (Analogue, Digital)
09	Graphical Information & Computer Graphics	19	Software Engineering
10	Information Processing	20	Language Technology
		21	Processing Technology

In addition, we show part of the data in this table in Figure 8-8 for the 21 subdomains. In the activity analysis, we observed that subdomain 21 (Processing Technology) is a spearhead of Flemish IT research. It is striking to see that this becomes visible here as well. The impact of 21 is above world average (above the diagonal), while the impact of the journals used in 21 is above the impact of the field (indicated in dark Grey). This means that the researchers in this subdomain are quite ambitious. Furthermore, the ambition of Flemish researchers and the impact of their publications in subdomain 15 (Process Control) is above world average.



Source data: Flemish IT publications covered by ISI databases. Citations to publications in a three year citation window. Size of circles (data points) indicate the proportional numbers of Flemish papers included in each subdomain, as related to the total number of Flemish papers in IT. Dark Grey data points are subdomains with a JCSm/FCSm > 1.2, light Grey are subdomains 0.8 < JCSm/FCSm < 1.2, white if < 0.8.

Subdomains:

01	Image Processing	11	Micro-electron. & General Electronic Techniques
02	Computer Aided Design	12	Multimedia Techniques
03	CIM & Production Control	13	Numerical Analysis & Applied Mathematics
04	Communication	14	Opto-electronics
05	Computer Architecture	15	Process Control
06	Educational Systems	16	Peripherals
07	Encryption & Security	17	Sensors & Actuators
08	Geographical Information Systems	18	Signal Processing (Analogue, Digital)
09	Graphical Information & Computer Graphics	19	Software Engineering
10	Information Processing	20	Language Technology
		21	Processing Technology

Figure 8-8 Overview of impact of Flemish IT publications per subdomain (1983-1991)

8.4 Concluding remarks

At this point, we wish to bring forward some aspects to be taken into consideration. The results of this bibliometric study were reported to the authority that commissioned this study in January 1994. Taking into account the duration of the project, the results were up-to-date. Since then, we only updated the citation data (i.e., the citations received by the IT publications from 1983-1992). Therefore, the results are in fact 'history' of IT research in Flanders. One might consider this as a weakness of bibliometric studies. However, it is a problem as far as publications in scientific journals are concerned. It will always take some time before the results of such a study are publicly available as a journal article. Therefore, the conclusions of this study, as far as the results are concerned, are somewhat outdated. The conclusions with regard to the methods are not.

In this study we proposed a procedure to evaluate an R&D field for its scientific and technological side. The study is primarily based on bibliographic data. To an as complete as possible picture, we combined data of scientific publications and citations, and patents. Moreover, we added input data retrieved from the OECD statistics (R&D expenditure, Population, and GNP) in order to compare the results for Flanders with those of Belgium and three neighboring countries. The study also relates this activity profile to overall developments in the field.

In general, the results present a clear picture of Flemish IT activity during 1983-1992. They show Processing Technology as a spearhead of Flemish IT research, as represented by the scientific publications. Furthermore, the results show Image Processing as a spearhead where patenting activity is concerned.

One of the main objectives of the study was to obtain this almost complete picture of the field and of Flemish activity as complete as possible. As a starting point, we took the publication and patenting activity. As mentioned above, the publication side and the patent side have different spearheads with regard to Flemish activity. Moreover, the study shows that Flemish IT researchers were generally very active on the publication side but not on the patenting side. Obviously, this is a choice made by the entire Flemish IT community. Of course, this will not lead us to the conclusion that Flemish IT researchers were not productive. Neither should we conclude that the results for the publication data indicate that Flemish IT researchers were better than scientists in other countries. The overall results, however, do show us that Flemish IT had a very characteristic activity profile during the studied period. The emphasis on publication activity is typical for Flanders, but a shift towards patenting has already been detected. Of course, other aspects have to be considered here in order to interpret these results from the proper perspective: particularly, industrial R&D infrastructure, regional publication/patenting culture. Countries or regions have different 'input' and therefore different 'output' characteristics. As a result, we argue that in studies like this one, patent and publication data should be analyzed together. Combined, they represent a country's output. At a later stage of study, differentiation can be useful to detect subdomains and topics with, for instance, high or low commercial potential.

From a bibliometrician's point of view, the problem arises as to how these different data sources should be combined. If we want to consider both a patent application and a learned publication as one unit of R&D production, we also need to find a way to break down all the 'products' over subdomains. In the present study patents and publications were grouped separately by using IPC and PACS codes. These two classification schemes differ from each other, so that the integrated results depend on the compatibility of the schemes. Moreover, the databases used, namely INSPEC and EPO, have such schemes, whereas others may not. Bibliographic fields (titles, abstracts, and authors/inventors, for instance) available for both data sources should be applied to accomplish this.

Furthermore, it should be noted that the publication and patent data are broken down over different subdomains by experts in the field of IT. Researchers at IWT have made a major effort to accomplish this. Obviously, these expert facilities are not available in every bibliometric analysis. An alternative approach would be to let the data generate its own structure (delimitation of subdomains). Thus, experts will only be needed to evaluate the results afterwards. At present, research is going on at CWTS to investigate the possibilities, advantages, and disadvantages of such an approach.

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9 Combining Mapping and Citation Analysis for Evaluative Bibliometric Purposes*

A bibliometric study on recent developments in Micro-Electronics, and on the performance of the Interuniversity Micro-electronics Centre in Leuven from an international perspective

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Combining Mapping and Citation Analysis for Evaluative Bibliometric Purposes

A bibliometric study on recent developments in Micro-Electronics, and on the performance of the Interuniversity Micro-electronics Centre in Leuven from an international perspective

Abstract

The general aim of the paper is to demonstrate how the results both of a structural analysis, and of a research performance assessment of a research field, can be enriched by combining elements of both into one integrated analysis. In addition, a procedure is discussed to select and analyze candidate benchmark institutes to assess the position of a particular research institute, in terms of both its cognitive orientation and its scientific production and impact at the international research front.

The combined method is applied in an evaluation of the research scope and performance of the Inter-university Centre for Micro-electronics (IMEC) in Leuven, Belgium. On the basis of the comments of an international panel of experts in micro-electronics, the method was discussed in detail. We concluded that the method provides a detailed and useful picture of the position of the institute from an international perspective. Moreover, we found that the results of each of the two parts are an added value to the other.

9.1 Introduction

In evaluative bibliometrics, two main procedures have been developed in the past decades. These two have, until now, always been used separately. The performance analysis, based on publication output and received citations, is used to assess the research performance of countries, universities, departments or persons. Early examples of these kinds of evaluative studies on a national level are Narin (1976), ABRC (1986), on the level of research institutes Martin and Irvine (1983) and Irvine and Martin (1985), and on the level of individual researchers Garfield (1983). Since the early years of these kind of science studies, the techniques have been improved and have gained an increasing role in policy support. An extensive overview and discussion of the state of the art is presented in Kostoff (1996), Narin and Hamilton (1996), Martin (1996), Van Raan (1997), Glänzel (1996), and Baird and Oppenheim (1994).

Mapping of science is the second procedure in evaluative bibliometrics, mostly aiming at displaying structural and dynamic aspects of scientific research (Braam, 1991). Maps of science have been created with different techniques. The co-citation technique was initiated by Henry Small at the Institute for Scientific Information (ISI) and further developed in the early seventies (Small, 1973; Small and Griffith, 1974; Griffith et al., 1974; and Garfield, Malin & Small, 1978). In the early eighties the co-word technique was introduced and further developed (Callon et al., 1983; Callon, Law & Rip, 1986, Law et al., 1988; Tijssen, 1992). The technique in general, as a tool for policy purposes, had to withstand severe criticism (e.g., Hicks, 1987; Oberski, 1988; Healey, Rothman & Hoch, 1986). A persistently returning point of criticism has been that the maps lacked of expert validation. At the start of this decade, combinations of both co-citation and co-word were developed (Braam, Moed & Van Raan, 1991; and Peters and Van Raan, 1993), partly to deal with the criticism. The main idea was to use one technique to validate the results obtained by the other.

In the present study, this idea is further developed, in the sense that results from one bibliometric approach are used to validate the results of another. We present the results of a combined performance/mapping study, used to evaluate a Belgian research institute in micro-electronics. At first, the combination was implemented to assess the activity and performance of the institute from both points of view. In a later stage, the combination was used to address the comments from experts to the study. As a result, we managed to use either procedure to validate the results of the other.

The Inter-university Micro-Electronics Centre (IMEC) in Leuven (Belgium) was founded in 1984 by the Flemish Government as an institute to perform scientific research which is five to ten years ahead of industrial needs. To fulfil this mission statement, IMEC has developed a strategy based on four guiding principles:

i. The establishment of an internationally recognized ‘Centre of Excellence’ in the field of micro-electronics;

ii. The performance of fundamental and strategic research in close collaboration with the Flemish universities;

iii. The performance of dedicated and flexible training programmes in the field of micro-electronics to both educational institutions and industrial companies;

iv. The reinforcement of industrial activities of companies based in Flanders.

In view of the renewal of the framework agreement for 1996 to 2000, the Flemish Government commissioned an audit of IMEC’s activities from 1984 until 1995. In order to provide background material for the Government in its negotiations with IMEC regarding the further elaboration of the new framework agreement, a bibliometric analysis of the research activity was conducted. It consisted of two main parts:

1. A study focussing on the worldwide trends in micro-electronics, and an assessment of the activity of IMEC in the field;

2. A study focussing on the research performance of IMEC in the field as compared to the performance of selected benchmark institutes.

The main objective of the study was to explore the potentials of a combination of these two aspects. The information added from one study to the other was expected to enhance the quality and applicability of both.

9.1.1 IMEC's organizational structure

IMEC was founded as a non-profit organization. Given its mission statement, IMEC's aim to match its long-term research strategy to the future needs of the (Flemish) industry is of crucial importance. To assist its scientific management in formulating this strategy, the IMEC has established a scientific advisory board. It is composed of ten members working either in academic institutions or in industry in Europe, Japan and the United States. This advisory board annually discusses IMEC's research strategy.

IMEC has a typical matrix structure. The study of basic technologies is organized in divisions:

- VSDM: design methodologies for Very Large Scale Integration (VLSI) systems;
- ASP: Advanced Semiconductor Processing;
- MAP: Materials and Packaging.

Each division contributes to the basic development of these technologies in collaboration with international partners. Many projects carried out at IMEC, however, make use of the technologies and are jointly executed by two or three divisions. A fourth division, Department for Industrial Training (INVOMEC), is responsible for IMEC's training activities.

The research and development activities of the Information Technology (INTEC) Laboratory of the Faculty of Applied Sciences at the University of Ghent (RUG), are fully coordinated with IMEC's activities in such a way that from a scientific point of view this research group can be considered as a division of IMEC. INTEC's research efforts are directed towards broadband communication, including opto-electronics and high-speed/ high-frequency circuits. In this study we investigated the three research divisions mentioned, plus INTEC, in as far as its research (output) is formally (addresses in publications) linked to IMEC.

9.2 Data, method and results

9.2.1 Publication data

In collaboration with the staff of IMEC, a database was created containing full bibliographic information (title, name, initials and working address of each author, source, volume, page, publication year) of all publications published during 1985-1994. The research output was represented by all publications in the IEE database on Physics, Electronics and Computing (INSPEC) and the Science Citation Index (SCI) with at least one IMEC address. We started with all the IMEC publications in INSPEC, which contains the addresses of the first author only. The database was completed by the IMEC staff with data from their own internal publication database. Part of these completing publications were covered by INSPEC as well, but were not selected before because the first address is not the IMEC. The INSPEC[17] information was added to these publications.

9.2.2 Citation data

For each publication, we collected data regarding the number of times it was cited until September 1995. This citation data was extracted from the on-line version of the SCI, produced by the Institute for Scientific Information (ISI). We determined the number of times a publication is cited per year. In addition, we counted the amount of self-citations separately. A self-citation is defined as a citation in a publication of which at least one author (either the first author or co-author) is also author of the cited publication.

9.2.3 Selection of benchmark institutes

In this evaluative performance analysis, IMEC’s results are compared to those of benchmark institutes. The data collected regarding these reference institutes is used for two different purposes. First, it enhances the standard performance analysis results based on IMEC’s publications and on the received citations. Normally, these analyses compare the results of a given institute to the world average. The present analysis compares the results of an institute with those of other, particular institutes. Secondly, the output of the benchmark institutes and their impact are used to characterize IMEC's publication activities. In this section, IMEC’s scientific output will be presented from an international perspective. The objective is to identify significant trends in the field, as defined by the publications of the IMEC and the benchmark institutes, and to analyze how IMEC's activities fit into this overall picture.

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[17] I.e. information added by the database producer, e.g. classification codes, and indexed terms.

The identification of benchmark institutes is a complex process. In view of the two applications mentioned above, there are several factors to be taken into account. On the one hand, a selected benchmark has to be active in the same field as the IMEC. On the other hand, the inclusion of benchmarks should allow us to have a somewhat broader view of the domain, in order to identify topics in which the IMEC is not, or hardly, actively pursuing. In addition, the size of the selected benchmarks should be comparable to the IMEC's.

We selected candidates using bibliometric techniques. In other words, the selection was made by comparing publication characteristics of institutes with those of the IMEC, in as far as they were included in the INSPEC database. The characterization of the IMEC's output was done by structuring its publications into areas of research. These areas were defined by clusters of classification codes. These clusters were obtained by co-occurrence clustering of the most frequent classification codes in publications of the IMEC in the period 1991 to 1994.

In the next step, we determined the number of publications produced by other institutes in these sub-domains, in as far as they were included in the INSPEC database in 1993[18].

The data per institute was enriched with three additional figures:

1. The number of sub-domains in which it has at least one publication;
2. The number of publications in each domain in which the IMEC is active;
3. The total number of publications of that institute in INSPEC (1993).

The ratio of figures 2 and 3 gives an indication of the scope, as compared to the IMEC's scope, and figure 1 indicates the 'output profile' similarity of an institute with the IMEC. Finally, the number of publications in INSPEC, gives an indication of the research capacity of the institute.

Based on a combination of these indicators, and taking a certain geographical spread, and a spread in the type of organizations (academic, firms etc.) into consideration, the following institutes were selected:

- NTT LSI Labs. at Kanagawa, Japan (NTT)
- Department of Electronic Engineering, National Chiao Tung University at Hsinchu, Taiwan (NCTU)
- Department of Electrical & Computer Engineering, University of Texas at Austin, TX, USA (UTA)

[18] As the INSPEC database includes data of the first author's address only, a publication of which the address of the second or third author is of a particular institute, is not assigned as such.

- Department of Electrical Engineering & Computer Science, University of California at Berkeley, CA, USA (UCB)
- Fraunhofer-Institut Für Angewandte Festkorperphysik at Freiburg, Germany (FHGF)
- Philips Research Laboratories at Eindhoven, The Netherlands (PHIL)

All of the institutes have a scope, which is more than 50 similar to the IMEC's scope. Three institutes have a scope of more than 85 overlap, two of about 65 overlap. The IMEC has about 100 publications per year. Four of the institutes have a similar output per year, two institutes have a publication output somewhat below this number. One of these institutes has increased its production during the period to match the IMEC's level[19].

9.2.4 Analyses

The publication database used in our analyses consists of two parts. One contains papers from INSPEC (database years 1989-1995) with one of the benchmark institutes in the address field, while the other part contains the earlier described the IMEC papers published in INSPEC (see section 9.2.1). Together, this data represents the research output of all those institutes within the field. From this database, we selected all papers published during the time period 1988 to 1994. In order to monitor trends in the field during these years, we broke them down into three 3-year blocks: 1988 to -1990, 1990 to 1992, and 1992 to 1994.

9.2.4.1 General trends in micro-electronics and actor analysis

To provide a visual representation of a large collection of publications (bibliographic data), the 'cognitive maps' are used, developed at the Centre for Science and Technology Studies (CWTS) (e.g., Braam, Moed & Van Raan, 1991; Van Raan & Tijssen, 1993; Peters & Van Raan, 1993, and Noyons & Van Raan, 1998). In such maps the vast amount of knowledge written in (scientific) publications is structured by means of a two-dimensional representation. The structure is generated from the

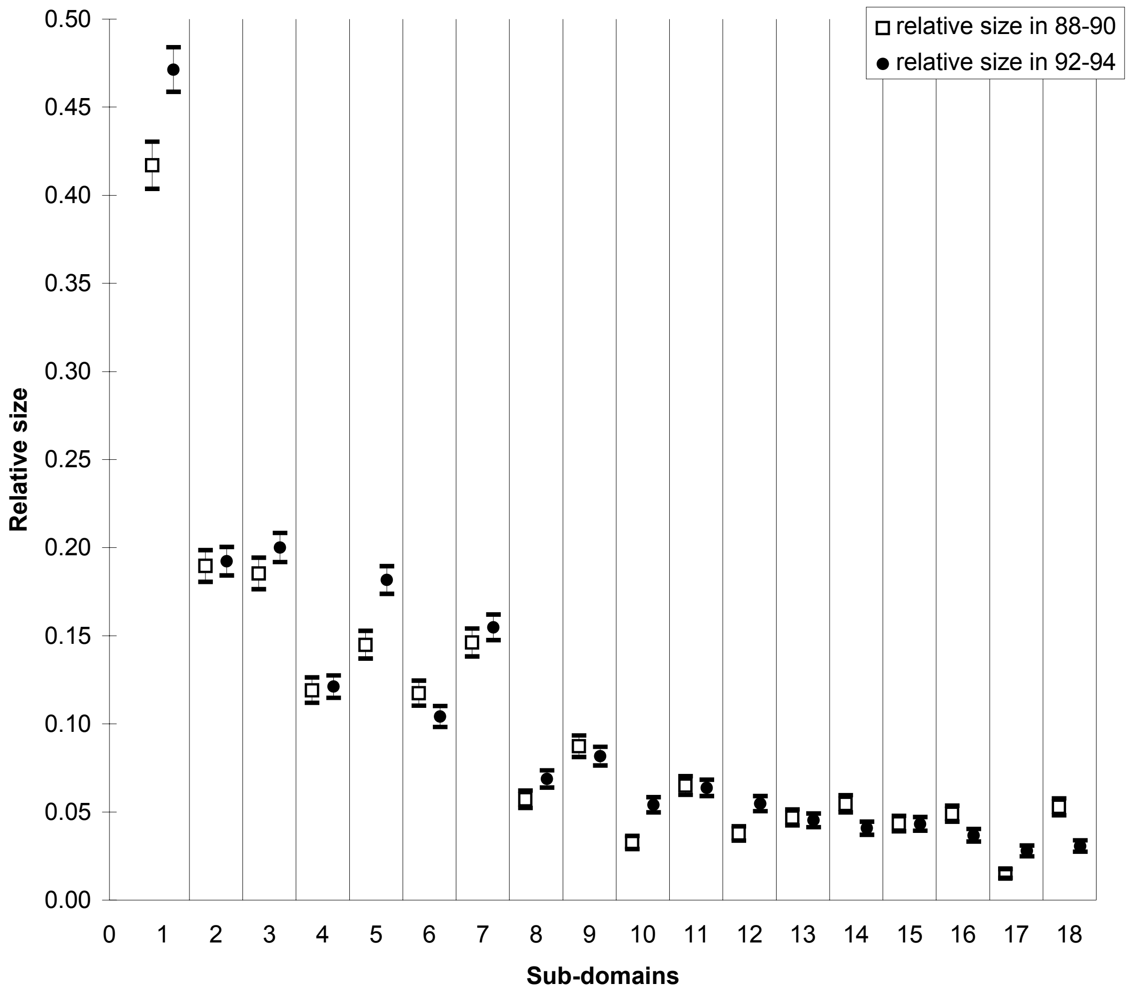
[19] In a later stage of the project, we also enhanced the database with information about the similarity of the scientific output of the benchmark institutes to that of IMEC. By selecting only those benchmark papers which had the same classification codes as IMEC's publications, a subset of publications considered to be closely related to IMEC's research was selected. In fact, we limited the output of the benchmark institutes to 2 levels of relatedness. Most related were those papers which had at least one of the 16 most important classification codes of IMEC in common (level 1). Second most related were those papers which had at least one classification code in common with the 69 most important codes from IMEC's papers (level 2). By making those selections, IMEC's output was also reduced to the core activities. The former (level 1), and most stringent, selection criterion reduced the overall output of the benchmark institutes by 60%, and IMEC's output by 30%. The latter, less stringent, selection criterion reduced the output of the benchmark institutes by 37% and IMEC's output by 8%.

data itself, rather than being derived from an existing (hierarchical) classification scheme. The research represented by the publications is dynamic. A structure based on an existing scheme does not leave room for identification of new developments, unexpected merging or splitting-up of areas and so on. Particularly, these aspects are of great importance to assess an actor's activity. Actors with a preference for areas that have an unexpectedly split-up or merger show a profile which differs from that of actors with a preference for more 'stable' areas. The map shows the structure of the most important sub-domains in a field. Each sub-domain seeks its own position on the map, taking into account its relations with *all* other on the map. The sub-domains are defined by sets of classification codes. The assignment of codes to sub-domains is established by the application of specific clustering techniques. The core classification codes (i.e. the most frequently used codes) of the field are clustered on the basis of their co-occurrences. The more two classification codes appear in the same publications, the more likely it is that they are clustered. The emerging clusters represent the mentioned sub-domains of the field.

The structure is derived from the 1992 to 1994 data (i.e., the most recent period, see Noyons and Van Raan, 1998). The definition of the sub-domains is given in Table 9–1. Per sub-domain, a set of classification codes is given. In the third column a characteristic name is given, referring to the most frequent classification codes in a cluster (sub-domain).

Table 9–1 INSPEC classification codes by cluster (sub-domain)

Sub-domain	*Classification Codes*	*Name*
1	B01, B22, B25	General Micro-Electronics
2	B12, C51, C52	Circuits & Design
3	A68, A81, B05	Materials
4	B11, C74	Circuit Theory
5	B02, B61, C11, C12, C41	Maths Techniques
6	A61, A64, A66	Liquids/Solids Structures
7	A71, A72, A73, A78	Electron. Struct/Propert Surfaces
8	A42, B43	Optics; Lasers & Masers
9	C42, C61	Computer Theory; Software Eng
10	B62, C56	Tele/Data Communication
11	A07, B72, B73	Measuring & Equipment
12	B41, B42	Optical/Optoelec Mat & Dev
13	C13, C33	Control Theory/Appl
14	A79, A82	Physical Chemistry
15	B13, B52	Micro/Electromagn Waves
16	B64, C53	Radio/TV/Audio; Computer Storage
17	A77, B28	Dielectric Propert/Mat/Dev
18	A74, A75	Supercond; Magn Propert/Struct



Subdomains:			
1	General Micro-Electronics	10	Tele/Data Communication
2	Circuits & Design	11	Measuring & Equipment
3	Materials	12	Optical/Optoelec Mat & Dev
4	Circuit Theory	13	Control Theory/Appl
5	Maths Techniques	14	Physical Chemistry
6	Liquids/Solids Structures	15	Micro/Electromagn Waves
7	Electron. Struct/Propert Surfaces	16	Radio/TV/Audio; Computer Storage
8	Optics; Lasers & Masers	17	Dielectric Propert/Mat/Dev
9	Computer Theory; Software Eng	18	Supercond; Magn Propert/Struct

Figure 9-1 Evolution of sub-domains (1988-1994)

In Table 9–2, the numbers of publications per sub-domain are given in the three successive two-year blocks investigated in this study. In Figure 9-1, we present an overview of the evolution of the sub-domains in terms of numbers of publications included in the most recent and 'oldest' year block of the studied period. Per sub-domain, the proportion of publications included relative to the total number in a period was calculated. Moreover, we calculated the error for both data points, under the assumption of a Poisson distribution. In this figure, we detect a significant increase in sub-domain 1 (*General Micro-Electronics*), 5 (*Maths Techniques*), 10 (*Tele/Data Communication*), 12 (*Optical/Optoelectronic Materials & Devices*), and 17 (*Dielectric Properties/Materials/Devices*) and an activity decrease in sub-domain 18 (*Supercond; Magnetic Properties/Structures*). In 14 (*Physical Chemistry*) and 16 (*Radio/TV/Audio; Computer Storage*) the relative decrease is beyond the error bars, but the absolute number of publications remain at the same level.

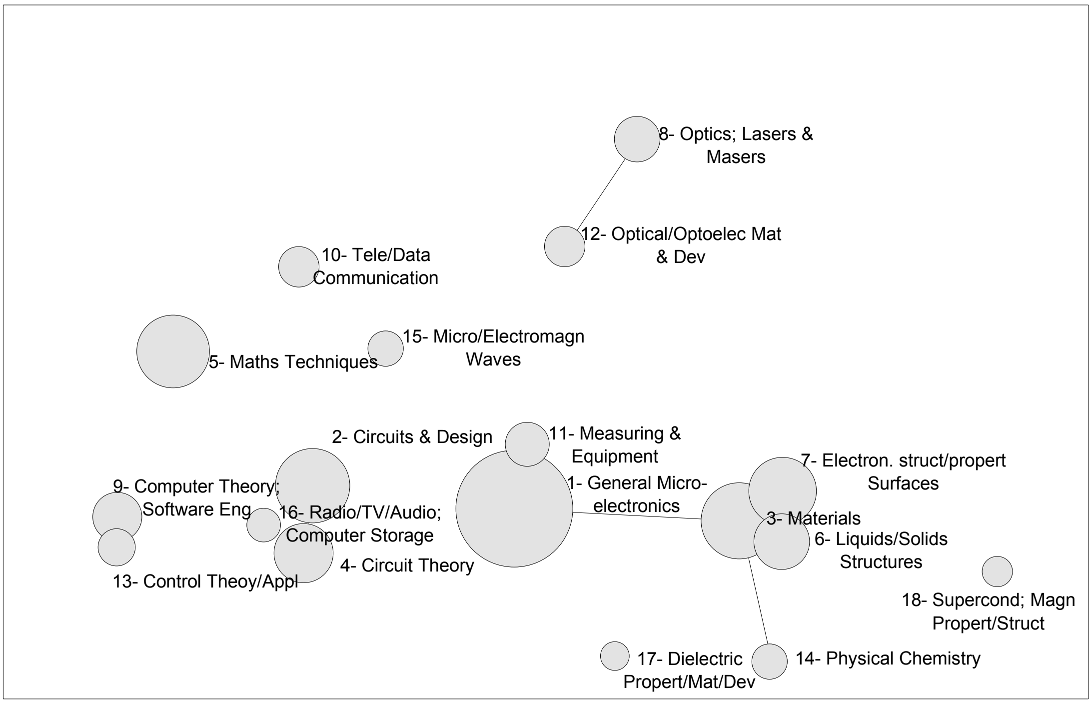
Table 9–2 Numbers of publications per sub-domain

Sub-domain	*Name*	*88/90*	*90/92*	*92/94*
1	General Micro-Electronics	970	1337	1385
2	Circuits & Design	441	537	565
3	Materials	431	529	588
4	Circuit Theory	277	340	356
5	Maths Techniques	337	480	534
6	Liquids/Solids Structures	273	299	306
7	Electron. Struct/Propert Surfaces	340	458	455
8	Optics; Lasers & Masers	133	182	202
9	Computer Theory; Software Eng	203	236	240
10	Tele/Data Communication	76	113	159
11	Measuring & Equipment	151	176	187
12	Optical/Optoelec Mat & Dev	88	128	161
13	Control Theory/Appl	109	128	133
14	Physical Chemistry	127	127	120
15	Micro/Electromagn Waves	101	124	127
16	Radio/TV/Audio; Computer Storage	114	122	108
17	Dielectric Propert/Mat/Dev	35	67	82
18	Supercond; Magn Propert/Struct	123	112	90

Figure 9-2 presents the cognitive structure of micro-electronics, as defined by the publications of the seven institutes covered by INSPEC. The relatedness of the sub-domains, based on the number of overlapping publications, is depicted by multidimensional scaling. The structure remains stable throughout the entire period of 1988 to 1994[20]. All sub-domains have approximately the same position every year. The most general or basic sub-domain (*General Micro-Electronics*) in the center of the map has sub-domain 11 (*Measuring & Equipment*) in its vicinity, with an agglomeration of sub-domains in the field of materials science (3: *Materials; 6: Liquids/Solids Structures*; 7: *Electronic Structures/Properties Surfaces*; 14: *Physical*

[20] A film of the interaction of sub-domains during the period can be viewed at http://sahara.fsw.leidenuniv.nl/ed/projects.html.

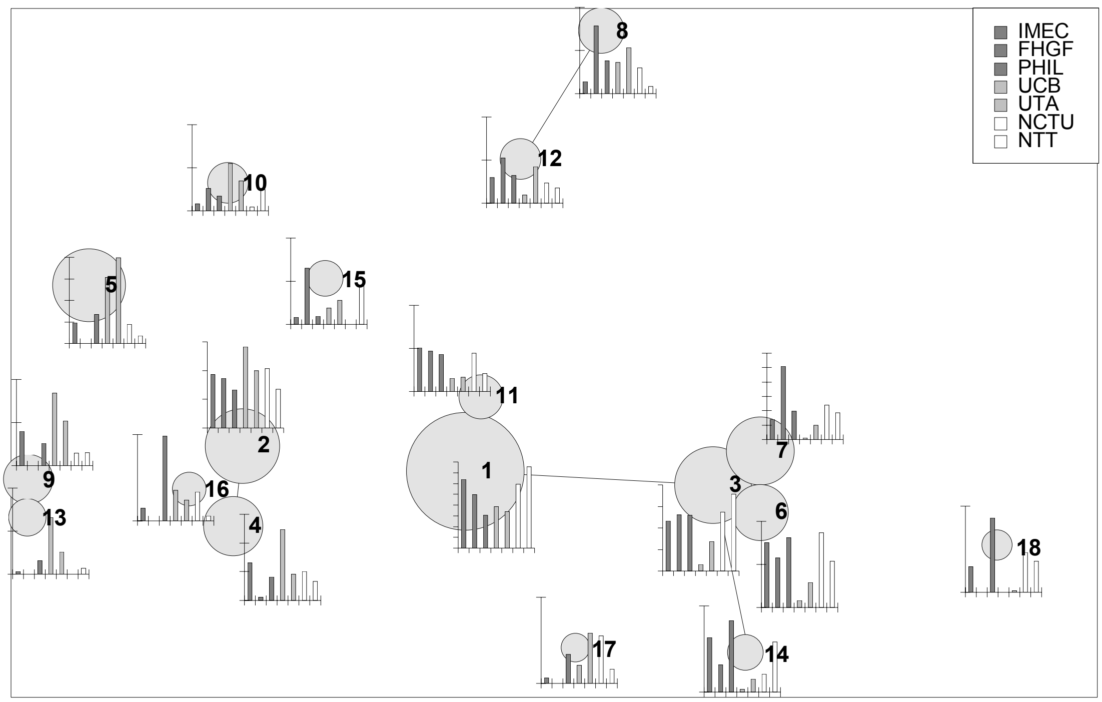
Chemistry; 17: *Dielectric Properties/Materials/Devices*; and 18: *Supercond; Magnetic Properties/Structures*) on the right-hand side. On the left-hand side, research topics on circuits (2: *Circuits & Design*; 4: *Circuit Theory*) can be found, and in their vicinity are sub-domain 16 (*Radio/TV/Audio; Computer Storage*) and related topics. In the upper part of the map, are sub-domains 8 (*Optics; Lasers & Masers*) and 12 (*Optical/Optoelectronic Materials & Devices*).



The circles in the map represent sub-domains in micro-electronics (1992/1994). The field is defined by the publications of the seven investigated institutes, covered by Inspec. The size of the circles represents the number of publications in a sub-domain. The distance between sub-domains is determined by the share of overlapping publications. Lines between indicate a relatively strong one on one relation.

Figure 9-2 general overview map of micro-electronics in 1992/1994 (Inspec)

In order to generate a general overview of the activities of the IMEC and of the benchmark institutes, we labeled the relative activity in 1992/1994 of the investigated institutes to the sub-domains in the map. The relative activity is defined the proportion of publications of an institute in a particular sub-domain relative to the whole number of publications by that institute. The results are plotted in Figure 9-3.



Subdomains: see legend Figure 9-1

Institutes	
FHGF	Fraunhofer Institüt für Angewandte Festkorperphysik at Freiburg, Germany
IMEC	The Flemish Interuniversity Micro-Electronics Centre, Leuven, Belgium.
NCTU	The Department of Electronic Engineering at the National Chiao Tung University at Hsinchu, Taiwan.
NTT	NTT-LSI Labs at Kanagawa, Japan.
PHIL	Philips Research Labs at Eindhoven, the Netherlands.
UCB	The Department of Electrical Engineering and Computer Science, University of California at Berkeley, USA.
UTA	The Department of Electronic and Computer Engineering, University of Texas at Austin, USA.

Figure 9-3 Actors in micro-electronics map (1992/1994)

The figure shows that each sub-domain has its own specific profile. On the lower right-hand side of the map (3 ,6 ,7 ,14 and 18), the activity of the two institutes in the United States is less prominent than in other areas. Their activity is mainly focussed on the left-hand side of the map (2: *Circuits & Design*, 4: *Circuit Theory*, 5: *Maths Techniques*, 9: *Computer Theory; Software Engineering*, and 13: *Control Theory/Applications*). The IMEC's activity focuses on the central area of the map.

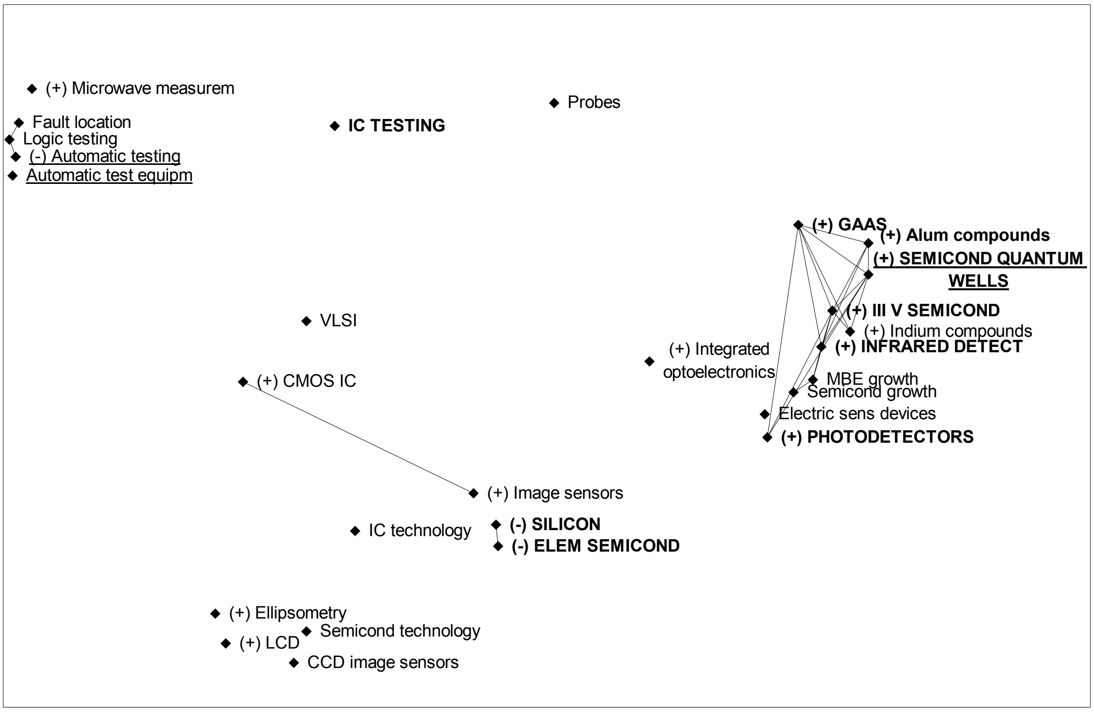
9.2.4.2 Fine-structure analysis

To obtain a more detailed overview of developments in the field and how IMEC's work fits in, we zoom in on the 18 sub-domains by creating co-word maps. These co-word maps are created for the year block 1992-1994 only, and are based on the co-occurrences of Controlled Terms (terms provided by the INSPEC database producer, and attached to the publications) within each sub-domain. The fine structure maps show related words close to each other, and words that are less related at a distance from each other. As an example, we present the fine-structure map of one of the 18 sub-domains. We added 'map-external' information to improve their applicability for evaluative purposes:

- a connecting line indicates a stronger than average link between two individual words, used to simplify, somewhat, the complex structure of the map;
- if a word is prominent for the sub-domain (more than 10 of the papers included), it is in bold print and capitals;
- if a word has an increasing interest within the same sub-domain during the period 1988-1994, it is preceded by a (+), if the interest is decreasing the word is preceded by a (-);
- words with *no* IMEC activity are underlined.

As an example we present the fine-structure map of sub-domain 11 (*Measuring & Equipment*). In this area, "Semiconductor Quantum Wells" is one of the topics for which there is a significantly growing interest. And although IMEC is very well represented in this area, it lacks activity on this particular topic. Furthermore, it is not very active on the subjects represented on the left-hand side of the map ("Automatic Testing" and related topics).

We emphasize that the maps describe the situation of IMEC's activity within this sub-domain. They do not prescribe what it should be. It may well be a strategy of IMEC not to publish about 'Automatic Testing' and 'Semiconductor Quantum Wells'.



Co-word map of a sub-domain, as defined by the publications of the seven institutes with the classification codes used to delimit it. Lines between words indicate strong linkages between two individual words. Words with a coverage of more than 10% of the publications are printed in bold face and capitals. Words with an increasing interest are preceded by a (+), and words with a decreasing interest by a (-). Words with no IMEC activity are underlined.

Figure 9-4 Fine-structure map of sub-domain 11, Measuring & Equipment

9.2.4.3 Performance analysis of the IMEC as compared to benchmark institutes

In the citation analyses, we calculated a range of bibliometric indicators. The first set is comprised of:

- An indicator of the number of publications published in a particular year or range of years. This indicator is symbolized by means of the symbol *P*. It is calculated for each institute and for each year during the time period 1989 to 1994.
- Moreover, for each institute we determined the percentage of publications, relative to the total number of publications published by all selected institutes aggregated (symbol: *%P*). We emphasize that the publication data analyzed in this section is extracted from the INSPEC database.

The next set of indicators relates to the impact of the publications.

- We calculated per institute the number of citations received by all publications during a time period starting with the publication year and ending with September 1995. Self-citations are not included (symbol: *Cex*).
- Moreover, for each institute we determined the percentage of citations received, relative to the total number of citations of all institutes (*%Cex*).
- The next indicator is the average number of citations per publication. Self-citations are not included (*CPPex*).
- We calculated the average number of citations for publications from all institutes. This statistic is indicated as *Overall Mean*. Using this statistic, we determined the ratio *CPPex/Overall Mean* for each institute. If this ratio exceeds 1.2 for a particular institute, the impact of the institute is qualified as high compared to the overall mean. If the ratio is below 0.8, the impact is considered to be low. The qualification "average impact" is given to institutes for which the ratio *CPPex/Overall Mean* is between 0.8 and 1.2.

The final set of citation-based indicators does not relate to the mean of the distribution of citations amongst publications, but to other parameters of that distribution.

- For each institute we calculated the number and percentage of publications not cited during the time period considered (symbols : Pnc and *%Pnc*, respectively).
- In addition, we identified the 10%most frequently cited publications in the collection of publications from all institutes in a particular year, by calculating the 90th percentile (*P90*) of the citation distribution. This parameter enabled us to determine the number and percentage of publications for each institute which were among the 10% most frequently cited publications from all institutes aggregated (*P|cit>P90* and *P|cit>P90*).
- Finally, for each institute we counted the number and percentage of publications which received more than 10 citations (*P|cit>10* and *P|cit>10*).

The basic question addressed in this section is: how does the scientific production and impact of IMEC compare to the output of the benchmark institutes listed in section 9.2.3? Scientific production is measured through the number of scientific publications published by researchers from an institute. Indications of the impact are derived from the number of times these publications are cited in international scientific literature.

The analyses presented in this section relate to data on scientific publications included in the INSPEC database. As outlined in section 9.2.1, from INSPEC we extracted all publications containing the names of IMEC or one of the benchmark institutes in the address field. Since INSPEC processes only the address of the *first* author of a publication, for each institute involved we selected only those publications of which the *first* author is located at that institute. Consequently, co-publications between the

IMEC and other institutes are included only if the first author is working at the IMEC. The same holds true for co publications of the benchmark institutes.

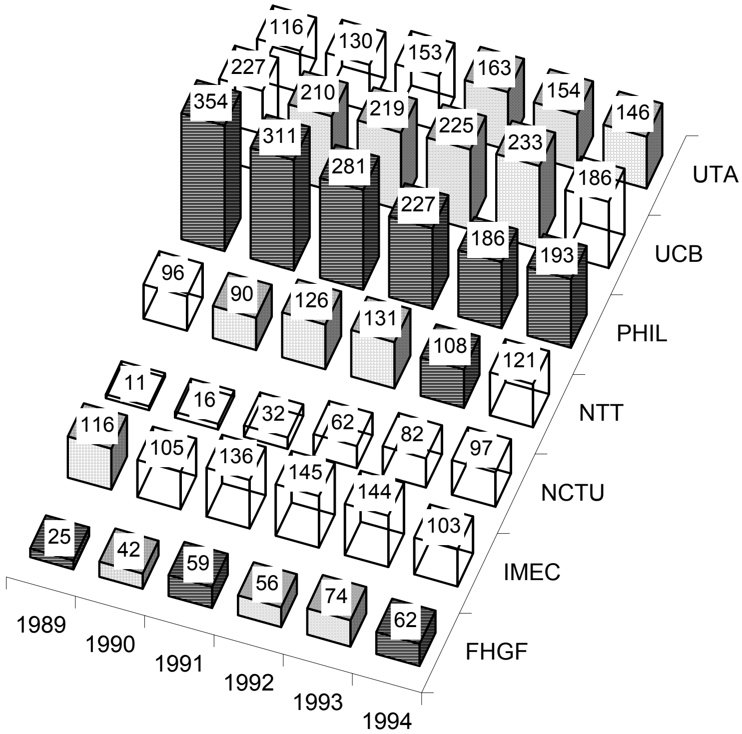
The publication data relate to the time period 1989 to 1994. However, it should be noted that the publication data of the year 1994 is incomplete. This is due to the fact that INSPEC processes publications with a certain delay. Publications published in 1994 but processed for the INSPEC database after April 1995 (i.e., the time the evaluation study was started) are not included. We estimated that we are missing about 10% of the publications with publication year 1994.

The results are presented in Table 9–3 and Figure 9-5. Table 9–3 shows the results for each institute with respect to publications published during the time period 1989-1993, as well as citations received until September 1995. As publications published in 1994 receive very few citations during the period before September 1995, these publications were not included in the results presented in Table 9–3. Figure 9-5 presents bibliometric scores per publication year. Since the figure shows the publications arranged by publication year, we decided to include the publications of 1994 as well.

Table 9–3 Bibliometric indicators for IMEC and benchmark institutes, based on INSPEC publication data

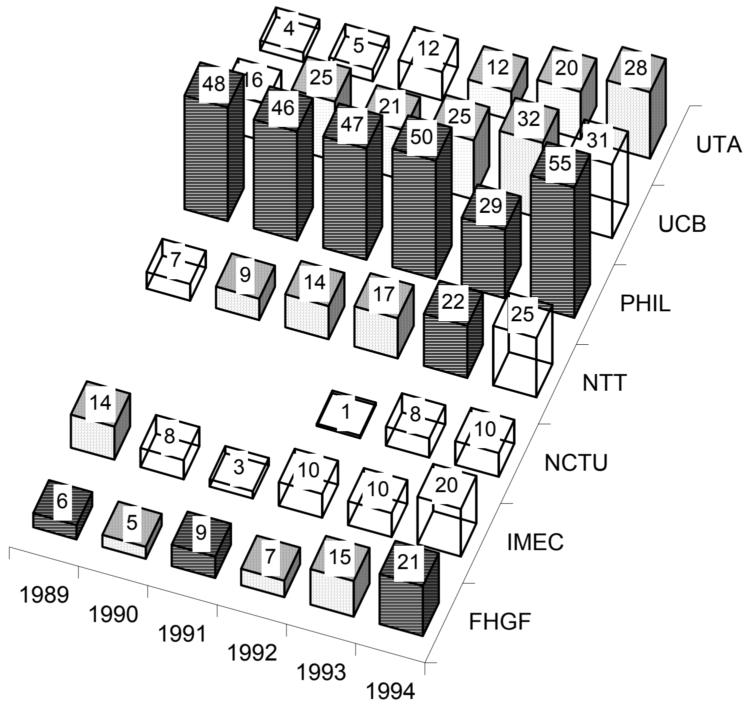
Indicator	*FHGF*	*IMEC*	*NCTU*	*NTT*	*PHIL*	*UCB*	*UTA*
P	256	646	203	551	1359	1114	716
% P	5.3	13.3	4.2	11.4	28.0	23.0	14.8
Cex	968	1345	135	1742	7403	3206	1518
% Cex	5.9	8.2	0.8	10.7	45.4	19.6	9.3
CPPex	3.8	2.1	0.7	3.2	5.4	2.9	2.1
CPPex/ Overall mean	1.1	0.6	0.2	0.9	1.6	0.9	0.6
Pnc	100	350	134	208	490	496	389
Pnc	39.1	54.2	66.0	37.7	36.1	44.5	54.3
P|cit>P90	29	36	0	56	231	101	47
% P|cit>P90	11.3	5.6	0.0	10.2	17.0	9.1	6.6
P|cit>10	26	32	0	49	206	89	39
% P|cit>10	10.2	5.0	0.0	8.9	15.2	8.0	5.4

P	:	The number of publications included in INSPEC and published during the time period 1989-1993
% P	:	The percentage of publications relative to the total number of publications published by all institutes
Cex	:	The number of citations received during a time period starting with the publication year and ending with September 1995. Self-citations are not included
% Cex	:	The percentage of citations received relative to the total number of citations of all institutes
CPPex	:	The average impact (number of citations) per publication. Self-citations are not included
CPPex/ Overall mean	:	The impact per publication relative to the average impact of the publications from all institutes
Pnc	:	The number of publications not cited during the time period considered
% Pnc	:	The percentage of publications not cited during the time period considered
P|cit>P90	:	The number of publications among the 10 percent most frequently cited publications from all institutes
% P|cit>P90	:	The percentage of publications among the 10 percent most frequently cited publications from all institutes
P|cit>10	:	The number of publications which receiving more than 10 citations
% P|cit>10	:	The percentage of publications more than 10 citations
FHGF	:	Fraunhofer Institüt für Angewandte Festkorperphysik at Freiburg, Germany
IMEC	:	The Flemish Interuniversity Micro-Electronics Centre, Leuven, Belgium.
NCTU	:	The Department of Electronic Engineering at the National Chiao Tung University at Hsinchu, Taiwan.
NTT	:	NTT-LSI Labs at Kanagawa, Japan.
PHIL	:	Philips Research Labs at Eindhoven, the Netherlands.
UCB	:	The Department of Electrical Engineering and Computer Science, University of California at Berkeley, USA.
UTA	:	The Department of Electronic and Computer Engineering, University of Texas at Austin, USA.



Publications from INSPEC and citations from SCI (time period 1989 - Sept. 1995). Numbers in the squares indicate the numbers of publications in INSPEC. Shading of the bars indicates the impact compared to the overall mean for all institutes aggregated. FHGF: Fraunhofer Institüt für Angewandte Festkorperphysik at Freiburg, Germany; IMEC: The Flemish Interuniversity Micro-Electronics Centre, Leuven, Belgium; NCTU: The Department of Electronic Engineering at the National Chiao Tung University at Hsinchu, Taiwan; NTT: NTT-LSI Labs at Kanagawa, Japan; PHIL: Philips Research Labs at Eindhoven, the Netherlands; UCB: The Department of Electrical Engineering and Computer Science, University of California at Berkeley, USA; UTA: The Department of Electronic and Computer Engineering, University of Texas at Austin, USA.

Figure 9-5 The Number of publications in INSPEC and their average impact per institute and per year



Publications from INSPEC and citations from SCI (time period 1989- Sept. 1995). Numbers in the squares indicate the numbers of publications in INSPEC among the 10 percent most frequently cited publications published in a particular year by all institutes aggregated. Shading of the bars indicates the impact compared to the overall mean for all institutes aggregated. FHGF: Fraunhofer Institüt für Angewandte Festkorperphysik at Freiburg, Germany; IMEC: The Flemish Interuniversity Micro-Electronics Centre, Leuven, Belgium; NCTU: The Department of Electronic Engineering at the National Chiao Tung University at Hsinchu, Taiwan; NTT: NTT-LSI Labs at Kanagawa, Japan; PHIL: Philips Research Labs at Eindhoven, the Netherlands; UCB: The Department of Electrical Engineering and Computer Science, University of California at Berkeley, USA; UTA: The Department of Electronic and Computer Engineering, University of Texas at Austin, USA.

Figure 9-6 The number of frequently cited publications in INSPEC per institute and per year

Table 9–3 shows that during the time period 1989 to 1993, the IMEC published 646 publications included in INSPEC and registered under IMEC's address. IMEC's output constitutes 13.3% of the total number of publications published by the IMEC and all benchmark institutes. The share of IMEC publications per year remains rather stable and only varies between 11% and 14%. Considering the total period 1989-

1993, the *Philips Research Laboratories at Eindhoven* appears to be the most productive institute in terms of INSPEC publications, followed by the *Department of Electrical Engineering and Computer Science at the University of California at Berkeley*. The share of *Philips* in the total publication output amounts to 28%. However, in Figure 9-5, it is shown that the absolute number decreased from 354 in 1989 to 186 in 1993. The contribution of the *University of California at Berkeley* decreased slightly, while *NTT-LSI* and the *Fraunhofer Institut für Andewandte Festkorperphysik at Freiburg* showed an increasing trend.

Considering the impact of the INSPEC publications from the various institutes involved, Table 9–3 and Figure 9-5 show that *Philips*' publications have the highest impact on the average. In fact, according to Table 9–3, the ratio of the impact of *Philips*' publications and the average impact of the publications from all institutes aggregated (*CPPex/Overall Mean*) amounts to 1.6. Figure 9-5 shows that this ratio is above 1.2 for each publication year separately. The ratio for IMEC is 0.6, which is equal to the value obtained by the *Department of Electrical and Computer Engineering at University of Texas at Austin*, and slightly lower than the *Department of Electronic Engineering at the National Chiao Tung University in Taiwan*.

The other impact indicators given in Table 9–3 and displayed in Figure 9-5, show that the IMEC and the *University of Texas at Austin* have similar results. With respect to publications published in 1989, the IMEC has published 14 publications among the t10% most frequently cited publications with publication year 1989 by all institutes aggregated (*P|cit>P90*=14). These 14 publications constitute approximately 12% of the IMEC publication output that year. In terms of impact of papers published during 1989-1993, 1989 is the IMEC's most successful year. In fact, in this particular year, IMEC occupies third position in the ranking of institutes, both with respect to the absolute number as well as to the relative percentage of publications among the 10% most frequently cited INSPEC publications.

As indicated in Section 2.3, the benchmark institutes were partly active in research topics in which the IMEC has hardly published anything. We analyzed whether the impact position of the IMEC compared to the benchmarks changed if only publications are considered about topics in which the IMEC was active. From the collection of INSPEC publications from the benchmarks we selected only those documents whose indexing terms closely matched the profile of the IMEC publications, applying several levels of correspondence. The outcome of the impact analyses based on these selected sets of publications was very similar to the one presented above.

9.2.4.4 Performance analysis of IMEC compared to world average

The analyses presented above relate to publications included in the INSPEC database and compare the IMEC's production and impact to a number of benchmark institutes.

In this section we address the following question: what is the IMEC's impact compared to the world citation average in the sub-fields in which the IMEC is active? The methodology applied in this section is identical to the one developed in several studies on the research performance of universities in Flanders (e.g., De Bruin et al., 1993). It is based on all of the IMEC's articles published in journals processed for the CD-ROM version of the SCI. For further details with respect to the methodology, we refer to the publications cited above. It should be noted that all co-publications between the IMEC and other institutes - and published in SCI journals - are included in this analysis. The results are presented in Table 9–4. The table shows that the total number of articles published by the IMEC during the time period 1984 to 1993 in SCI journals amounts to 599. These articles are cited 1381 times from 1984 to 1993. The Institute for Scientific Information (ISI) has classified journals into sub-fields or journal categories. For the IMEC, the most important sub-fields are: *Applied physics* (198 articles); e*lectrical engineering* (117 articles); c*ondensed matter physics* (60 articles); *general physics* (39 articles) and *chemical physics* (27 articles).

Table 9–4 Impact of IMEC articles published in SCI journals

Indicator	*Score*
Nr. SCI publications in 1984-1993	599
Citations during 1984-1993 to SCI publ., self-citations not included	1381
Citations per SCI article, self-citations included	3.5
Citations per SCI article, self-citations not included	2.3
World citation average	2.6
Average impact journal packet	2.9
Impact compared to world citation average	1.3
Impact compared to average impact journal packet	1.2
Impact journal packet compared to world citation average	1.1

Taking into account the distribution of the IMEC's articles among sub-fields, we calculated the average impact of papers in all sub-fields in which the IMEC is active. Comparing the IMEC's impact to this world citation average, we obtained a ratio of 1.3. This means that the IMEC's articles have an impact which is a factor of 1.3 higher than the average impact of all articles in the sub-fields in which the IMEC is active. If we compare the impact of the IMEC articles to the average impact of all papers in the journals in which the IMEC has published, we found a ratio of 1.2. Finally, the impact of the journals in which the IMEC has published is 1.1 times higher than the world citation average in the sub-fields covered by these journals.

9.2.4.5 Research performance of IMEC's divisions

In this section, we present the results of the analyses based upon IMEC's total publication output. We give results regarding the production, productivity and impact of IMEC during the time period 1985 to 1994. In addition, we present the outcomes per division. The production and impact indicators applied in this section are similar to those presented in section 9.2.4.3. For a more detailed methodological discussion on these indicators, we refer to that section.

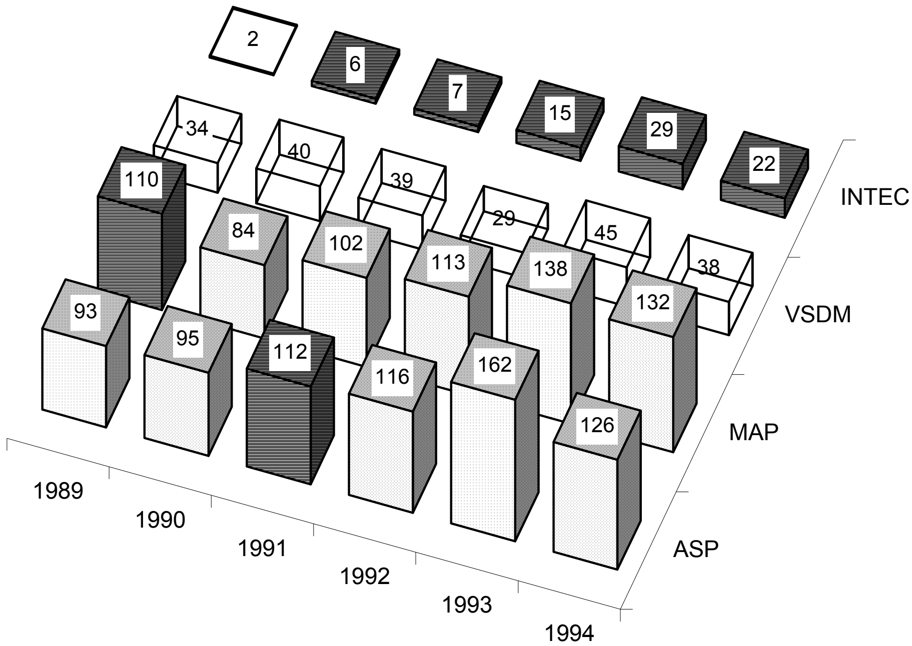
The main results per IMEC division are summarized in Table 9–5 and Figure 9-7. Table 9–5 gives the results for each IMEC division regarding publications published during the time period 1989 to 1993, and citations received until September 1995. Figure 9-7 presents the bibliometric scores per publication year.

Table 9–5 Bibliometric indicators for IMEC by division

Indicator	*ASP*	*INTEC*	*MAP*	*VSDM*	*Rest*
P	578	59	547	187	25
% P	41.4	4.2	39.2	13.4	1.8
Cex	1033	120	1128	124	49
% Cex	42.1	4.9	46.0	5.1	2.0
CPPex	1.8	2.0	2.1	0.7	2.0
CPPex/ Overall mean	1.0	1.2	1.2	0.4	1.1
Pnc	312	25	309	42	14
Pnc	54.0	42.4	56.5	75.9	56.0
P|cit>P90	6	9	6	7	3
% P|cit>P90	11.2	15.3	12.1	3.7	12.0
P|cit>10	26	2	26	2	1
% P|cit>10	4.5	3.4	4.8	1.1	4.0

P: The number of publications published during the time period 1989-1993 (all types of publications included); %P: The percentage of publications relative to the total number of publications published by all IMEC divisions; Cex: The number of citations received during a time period starting with the publication year and ending with September 1995. Self-citations are not included; %Cex: The percentage of citations received relative to the total number of citations to all IMEC divisions aggregated; CPPex: The average impact (number of citations) per publication. Self-citations are not included; CPPex/Overall mean: The impact per publication relative to the average impact of the publications from all IMEC divisions aggregated; Pnc: The number of publications not cited during the time period considered; %Pnc: The percentage of publications not cited during the time period considered; P|cit>P90: The number of publications among the 10 percent most frequently cited publications from all IMEC divisions aggregated; %P|cit>P90: The percentage of publications among the 10 percent most frequently cited publications from all IMEC divisions aggregated; P|cit>10: The number of publications which received more than 10 citations; %P|cit>10: The percentage of publications which received more than 10 citations.

ASP: Advanced Semi-Conductor Processing; INTEC: The Department of Information Technology at the University of Ghent; MAP: Materials and Packaging; VSDM: Design Methodologies for VLSI Systems; Rest: All other divisions



All types of publications included. Citations from SCI (time period 1989- Sept. 1995). Numbers in the squares indicate the number of publications. Shading of the bars indicates the impact compared to the overall mean for all IMEC divisions.
ASP: Advanced Semi-Conductor Processing; INTEC: The Department of Information Technology at the University of Ghent; MAP: Materials and Packaging; VSDM: Design Methodologies for VLSI Systems.

Figure 9-7 The number of publications and their average impact per IMEC division and per year

The divisions ASP and MAP have published 547 and 578 publications, respectively. These two divisions account for approximately 81% of all the IMEC publications. The share of publications from VSDM researchers amounts to 13%. About 25 researchers are on the IMEC's payroll but actually work in the INTEC Laboratory at the University of Ghent. They have published 59 documents, which constitute 4% of the IMEC's total publication output.

Considering the impact indicators, Table 9–5 and Figure 9-7 show that ASP and MAP publications have generated rather similar impacts on the average. The impact of the

VSDM documents is lower than that of these two divisions. According to Table 9–5, the impact of scientists on the IMEC payroll and working at INTEC is higher than that of the other IMEC divisions.

9.3 Comments of experts and additional analysis

9.3.1 Introduction

In this section, we discuss the comments of researchers in the field given at the end of the evaluative bibliometric study. We collected these comments in discussions with the staff of the IMEC, and researchers in the field from the IMEC and other institutes in Europe and the United States. The comments were collected to evaluate the potentials of evaluative bibliometric studies and to improve their quality. Moreover, we present results of additional analyses, aiming at validating the results of the conducted studies.

9.3.2 Comments of experts

In general, two main issues were raised. Firstly, the experts found the maps a useful tool but had difficulties with locating their own research (relocatability). It was suggested that this might be due to the limitations of the classification scheme of INSPEC, on which the coarse structure of the field was based. They found it difficult to link their own work to classification codes. They questioned the usefulness of the classification scheme to structure the field.

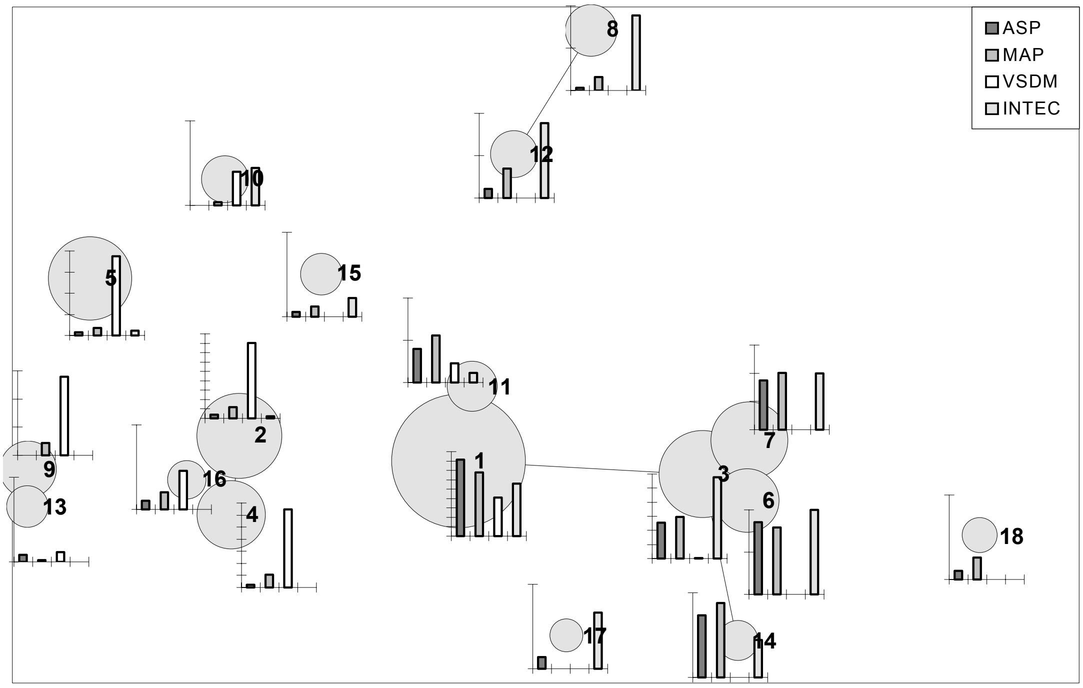
Secondly, the experts emphasized the role of the researchers' publication strategy. On the one hand, the IMEC and other strongly industry-related institutes tend more and more to present their research results at conferences and in proceeding papers. On the other hand, institutes with a formal academic link still attribute great value to publishing their results in scientific journals. A study based on publications from both kinds of institutes seems to disclose results from two different 'worlds'. In the first place, because the publication delay of scientific (refereed) journals is much longer than the delay of proceeding papers. The time periods in our studies are based on the publication date of the articles, so that the research results represented in period *t* originate from different periods before *t*. In the second place, the performance analyses are based on citations to publications. It is a well-known fact that the impact of journal articles is on average much higher than the impact of proceeding papers. By comparing the performance of institutes with different publication strategies, we seem not to be comparing like with like.

9.3.3 Relocatability

We implemented several adjustments to the 'older' maps aiming at improvement of the relocatability of topics and publications. One of the adjustments concerns the digitalization of the maps. The maps have been made clickable' so that a user (e.g., researcher) can easily zoom into sub-domains and to the publications represented by topics in the sub-domain maps (cf. Figure 9-4). Moreover, we developed a graphical interface to "click" from authors' addresses to sub-domains and thereon to topics[21]. It should be noted that such "tools" are not easily applicable to a map on paper.

Moreover, we compared the map structure of micro-electronics to the internal structure of the IMEC in order to investigate the relocation potentials of the map. In Figure9-8, an overview is given of the proportional presence of each of the four publishing IMEC divisions in the map, based on co-classification (cf. Figure 9-2). The map shows that the research of the four divisions can be relocated in different areas. VSDM can be found mainly on the left-hand side (2: *Circuits & Design*, 4: *Circuit Theory*, 5: *Maths Techniques*, and 9: *Computer Theory*; *Software Engineering*). The specialties of INTEC's activity within IMEC is at the top of the map (8: *Optics; Lasers & Masers*, and 12: *Optical/Optoelectronic Materials & Devices*). And the research of ASP and MAP, and some of the work of INTEC is found just outside the center of the map on the right-hand side (3: *Control Theory/Applications*, 6: *Liquids/Solids Structures*, 7: *Electronic Structures/Properties Surfaces*, and 14: *Physical Chemistry*). Not surprisingly, the activity of all divisions is high in the center of the map (1: *General Micro-Electronics*). Besides their usefulness for relocatability, these results show that the structure of the field represented by co-occurrences of classification codes corresponds rather well to the internal structure of the IMEC. Hence, it seems that the structure is appropriate to structure the research output of the IMEC, although the description of the classification codes is not sufficiently specific for researchers to recognize their own work.

[21] Examples of such digital maps are demonstrated at the WWW-page of CWTS (http://sahara.fsw.leidenuniv.nl).



Circles in the map represent sub-domains in micro-electronics. Their size represents the proportional number of publications included. The column charts per sub-domain represent the publication profile of the three main divisions of IMEC. The value is determined by the ratio of publications of a division in a sub-domain and the overall production of that division.

Subdomains:

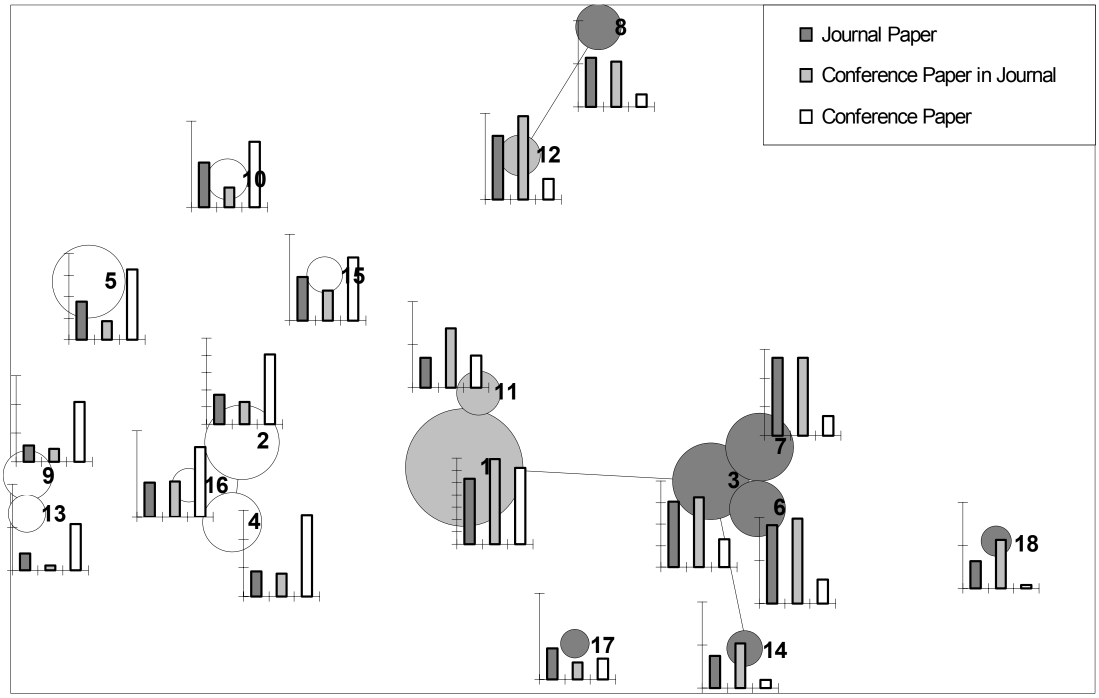
1	General Micro-Electronics	10	Tele/Data Communication
2	Circuits & Design	11	Measuring & Equipment
3	Materials	12	Optical/Optoelec Mat & Dev
4	Circuit Theory	13	Control Theory/Appl
5	Maths Techniques	14	Physical Chemistry
6	Liquids/Solids Structures	15	Micro/Electromagn Waves
7	Electron. Struct/Propert Surfaces	16	Radio/TV/Audio; Computer Storage
8	Optics; Lasers & Masers	17	Dielectric Propert/Mat/Dev
9	Computer Theory; Software Eng	18	Supercond; Magn Propert/Struct

ASP: Advanced Semi-Conductor Processing; INTEC: The Department of Information Technology at the University of Ghent; MAP: Materials and Packaging; VSDM: Design Methodologies for VLSI Systems.

Figure 9-8 Position of IMEC divisions in map (1992/1994)

9.3.4 Publication strategy

In the discussion with the experts in micro-electronics, the issue was raised of the strategy of institutes and of the IMEC's divisions to publish their papers, and the effect on impact of their work. Industrial-related institutes tend to present their work at conferences, whereas institutes with a more academic-related character, attribute great value to publishing their work in learned journals. As conference proceedings on average receive fewer citations than journal articles, this will have its effect on the impact figures of each individual institute, and even of each individual division.



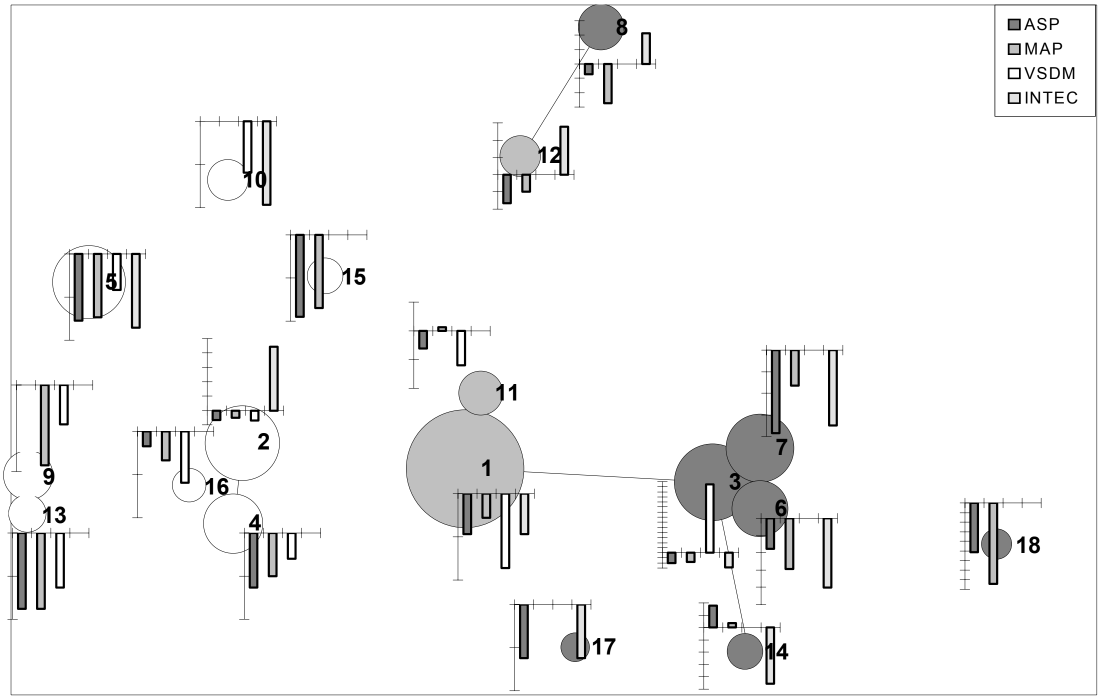
Subdomains: see Figure 9-8. Circles in the map represent sub-domains in micro-electronics. Their size represents the proportional number of publications included. The column charts per sub-domain represent the relative number of publications per document type. The value is determined by the ratio of publications per document type in a sub-domain and the overall number of publications of that type in the field. The shading of the circles indicates the average impact in a sub-domain (white if CPP < 2.1, dark Grey if CPP > 3.2).

Figure 9-9 Proportional distribution of document types in micro-electronics map, and average impact per sub-domain

The situation in micro-electronics is illustrated by Figure 9-9. The structure of the map reveals both to the distribution of document types and to the impact of micro-electronics publications. On the left-hand side, eight sub-domains are located with a relatively high number of proceedings papers with an impact below average, whereas on the right-hand side of the map we find the sub-domains with a relatively high number of journal papers with an impact above average. Again, we found an objective support for the obtained co-classification structure. The structure corresponds to the distribution of document types in the map and therefore, according to the experts' comments concerning publication strategy, it is strongly related to the character of the research: industry-related on the left, academic-related on the right hand side of the map. As a result, the structure appears meaningful, particularly in combination with the results of Figure 9-8. Moreover, the results support the observation of the experts that the impact figures should be treated with great care because of the differences among document type of the cited item and among the areas in which the paper is published. The structures represented by the maps reveal large differences between sub-domains with regard to average impact and usage of document types.

The fine-tuning of impact data using the field structure on the one hand and the break-down of documents over IMEC's divisions, enable us to assess more accurately the impact per division. Within each sub-domain, the overall results will then become more valuable.

In Figure 9-10, we plotted the impact per division relative to the average impact in a sub-domain. The figure shows that in general the impact IMEC is somewhat below the average of all investigated institutes. This consists with the findings in Figure 9-5. In some cases, however, the impact of IMEC divisions is above the average. In sub-domains 2 (*Circuits & Design*), 8 (*Optics; Lasers & Masers*) and 12 (*Optical/Optoelectronic Materials & Devices*), the impact of INTEC is above average and in sub-domain 3 (*Materials*) the impact of VSDM is above average. This observation is remarkable, taking the interest of VSDM in consideration. In Figure 9-8, we saw that VSDM mainly focuses on the area on the left hand side of the map. In this particular area, the impact of VSDM is in most cases higher than the impact of the other IMEC divisions, although still below the average. The impact of ASP and MAP is always just below the average. In their area of interest (right-hand side of the map), the overall average impact is relatively high (dark Grey circles).



Legend, subdomains and divisions: see Figure 9-8.

Figure 9-10 Impact of papers per IMEC divisions related to sub-domain average

9.4 Concluding remarks

At the end of most bibliometric studies for evaluative purposes, experts in the evaluated field and/or users of the results have the opportunity to give their comments and recommendations. Through these comments, experts make important contributions to the development of bibliometric tools. In this study, we used the comments and recommendations to improve the quality of some of the existing indicators by combining two bibliometric applications. We found that the mapping procedure can enhance the impact analyses in order to investigate the performance in a research field in more detail. On the other hand, the impact figures contribute to validation of the structures obtained by bibliometric mapping. The structure in the field of micro-electronics generated by co-classification mapping of publications, corresponds to a large extent to a (hidden) structure based on citations received by these publications. The combined procedure provides a monitoring tool for research performance on a detailed level, taking into account recent developments in the field.

Thus, a bibliometric picture can be obtained of an actor (e.g., country, university, department) compared to its peers and from a dynamic perspective at once.

Several comments gathered from experts and users of the study still have to be investigated. The most important one is the claim that the research topics covered by proceeding papers differ from those covered by journal articles. Although we found that the distribution of document types highly correlates with the structure based on classification codes, this is still an issue to be studied in more detail. At the least, the publication delay of the latter type of documents seems problematic. By comparing the dynamics of a subset of proceeding papers on the one hand and journal articles on the other, we intend to study this matter in the near future. An additional requirement will be that the structure is obtained by analyzing words in abstracts, rather than using classification codes and controlled terms (of INSPEC). The structure of a field will then stay even closer to the most recent (and "actual") developments.

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Part III New Developments in Science Mapping

In Part I the use and problems of map validation and utilization have been described. In Part II, the evolution of the science mapping tool for a science policy and research management, as developed at CWTS, has been depicted on the basis of six case studies. Each study has been used to illustrate a particular aspect or problem of this tool. In Part III the present developments of science mapping are further described. Although we are well aware of the fact that much still has to be developed, the procedures proposed in this part, are an important step ahead towards science mapping as a useful tool to evaluate science and its actors.

The 'state of the art' of science mapping as science policy tool is given by an analysis of our own field, being quantitative studies (scientometrics, informetrics and bibliometrics - SIB). The results of this study were made accessible on Internet, and could be evaluated by 'visitors' by means of a feedback form. In the discussion of the study, we incorporate these comments as well as the comments raised at the Science & Technology Indicators Conference 1998, at Cambridge University, where the study was presented. Thus, it was possible to evaluate the added value of the proposed improvements.

Furthermore, an opportunity for future improvement and application of science mapping is discussed. It relates to the procedure of selecting keywords from titles and abstracts for the purpose of structuring publication databases for science studies. With the advent of electronic publishing of scientific research, the role of scientific journals in the present form is at stake. Moreover, the creation and update of database-specific thesaurus terms will become problematic. As a result, it will become more difficult to maintain an overview of developments in a research field, let alone of science as a whole. The proposed method in Chapter 11, aims at identifying keywords and topics in a research field to be used to structure it. These keywords are filtered from titles and abstracts of publications delineating the field. Thus, science mapping becomes independent from publication databases and databases-specific facilities (e.g., classification schemes and thesauri).

In Chapter 12, the perspectives for evaluative bibliometrics, and science mapping in particular, are touched upon.

10 'State of the Art': A Case Study of Scientometrics, Informetrics and Bibliometrics[22]

In this chapter, the results of a mapping study in the field of Scientometrics, Informetrics, and Bibliometrics (SIB) are presented. This field may also be called more generally 'quantitative studies of science'. During the study, we found that the delineation is not as simple as it seemed beforehand. A study published in the same period of time as our study was performed (White & McCain, 1998), showed that SIB researchers may all have their own way of describing the field. Therefore, by allowing the researchers in the field to define the field themselves, we could finally suggest a selection procedure of publications to which they agreed.

By mapping our own field, we have field experts readily at hand. Thus, we were able to validate rather easily the structure as well as the utility of the map interface. Given the fact that the experts were so closely involved, we could explore on the basis of their comments, possible new developments and perspectives for science mapping. We will report about these explorations in this chapter.

10.1 Field delineation, data collection, and methodology

Mapping your 'own' field, has the advantage of experts being directly available (colleague-researchers at CWTS). In addition, it is expected to be easy to attract other experts to evaluate the results (colleague-researchers worldwide in the field of SIB). On top of that, the policy-relatedness of SIB, draws researchers working in political organizations, so that the (policy-related) users are involved as well.

The first step of the study concerned the delineation of the field on the basis of opinions of the researchers in the field. For this purpose, we addressed an Internet discussion list of researchers being member of the International Society for Scientometrics and Informetrics (ISSI). This forum of about 200 members contains researchers in the SIB field. Part of them is working in research policy-related organizations. They were asked to provide names of journals that belong to the core of the field. Secondly, they were asked to list the most important keywords or terms of their own research. About 20 researchers (10%) returned a list. Although the responding rate was not very high[23] most of the supplied information was valuable.

Second, the aggregated list of suggestions was proposed to the forum again and they were asked to give their reactions to the list. This step was built in to check the

[22] An internet version of this project is available at: http://sahara.fsw.leidenuniv.nl.

[23] The main reason for the low response is the fact that the survey was sent to the electronic discussion list. Colleagues could send their suggestions to my personal e-mail address but chose to send them to the discussion list so that all possible respondents could read the contributions by the earlier respondents. Once 'their' suggestions were already proposed by these earlier respondents, they did not feel the urge to contribute as well.

validity of the suggestions and to get rid of journals with too general a scope. Finally, we selected journals fully covered by the Social Science Citation Index (SSCI) only, in view of the planned impact analyses. As a result, eleven journals were selected. We collected the 1991 to 1997 bibliographic data of all publications in these journals, and took that as a starting point for our analyses.

The set contains the following journals:

- Information Processing & Management;
- International Information & Library Review;
- Journal of Documentation;
- Journal of Information Science;
- Journal of the American Society for Information Science;
- Library and Information Science;
- Research Policy;
- Science Technology & Human Values;
- Scientometrics;
- Serials Librarian;
- Social Studies of Science.

As we were able to retrieve the abstract data for the publications of 1992 to 1997, we based our analyses on these years. The basic structure of the field was derived from the 1995/1997 data and the period of 1992/1994 was studied as well.

The titles and abstracts of articles, letters, notes and reviews in the selected journals were subject to a linguistic analysis and the noun phrases were extracted (for details, see Chapter 11). For the most recent period (1995-97), the most frequent noun phrases were identified and used as a list of 'candidate field-specific keywords' representing the core of SIB. On the basis of the expertise at CWTS, a subset of 52 field keywords was selected from this list to be used to structure the field. By calculating the co-occurrences of these keywords, and normalizing the 'raw' co-occurrence matrix with the cosine of co-occurrence vectors, we created a matrix containing the similarity data of the keywords in terms of their cognitive orientation. Thus, keywords with a similar co-occurrence profile (with all other keywords) have a high similarity index (Noyons and Van Raan, 1998a).

$$sim(x,y) = \frac{\sum_i (x_i y_i)}{\sqrt{((\sum_i x_i^2)(\sum_i y_i^2))}}$$

where:
x_i = number of co-occurrences of keyword x with any other keyword
y_i = number of co-occurrences of keyword y with any other keyword

Cosine vector of co-occurrences

This similarity matrix was object to a cluster analysis in order to identify clusters of cognitively related topics. The cluster analysis yielded five clusters. This is locally an optimal solution based on the combination of three criterions to determine the 'ideal' number of clusters (c.f., SAS User's Guide, 1989).

The keywords clusters delineate subdomains of SIB. Publications representing the subdomains are retrieved by the keywords. Thus, the keyword clusters denominate subdomains of SIB.

As publications may represent more than one subdomain, we can use the overlap between subdomains (in terms of common publications) as input for multidimensional scaling (MDS). The resulting two dimensions of MDS yield the map of SIB. In the map subdomains with a similar cognitive orientation (many common publications) are in each other's vicinity, and those with a different orientation are distant from each other. In our case, the map (based on the cosine vector co-occurrence data) represents a 'perfect' solution for the cluster co-occurrence data (badness-of-fit: 0.00; distance correlation: 1.00).

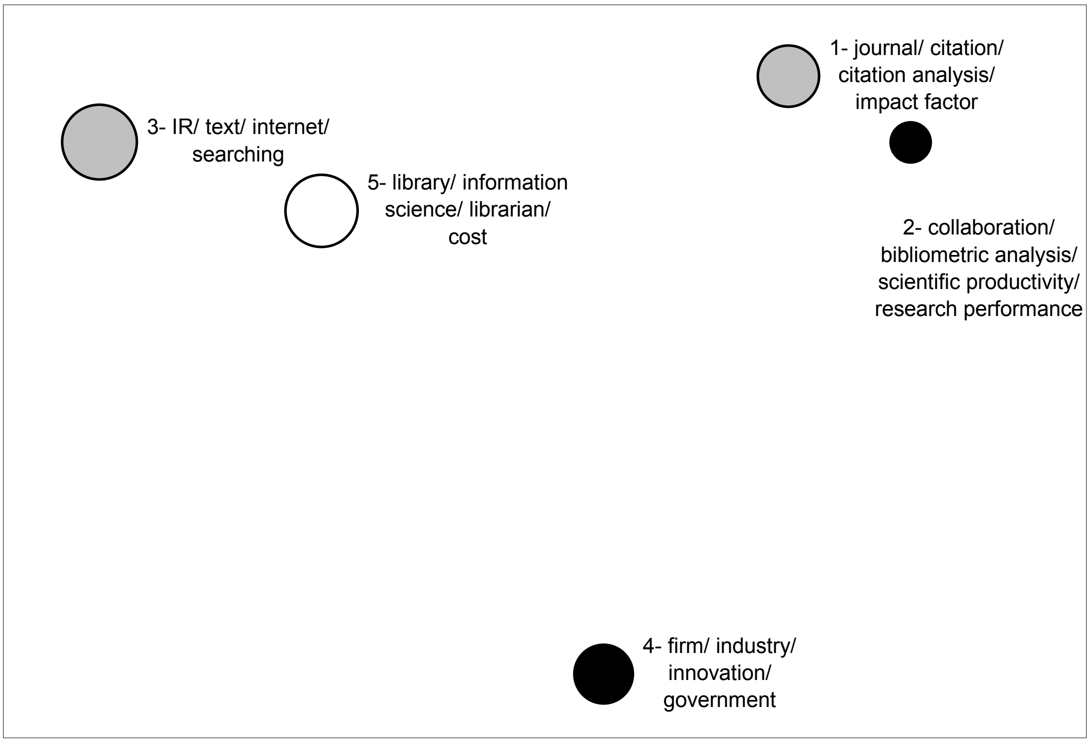
10.2 Main results

As discussed above, our clustering analysis of the 52 keywords yielded five subdomains within SIB. In order to identify the contents, we assigned to each of these subdomains a name based on the four most prominent (i.e., the most frequent) keywords within.

Table 10–1 Five identified subdomains in SIB (1995-97)

Cluster	*Nr Pubs 1992-94*	*Nr Pubs 1995-97*	*Subdomain name*
1	157	172	journal/ citation/ citation analysis/ impact factor
2	48	73	collaboration/ bibliometric analysis/ scientific productivity/ research performance
3	174	245	IR/ text/ internet/ searching
4	71	156	firm/ industry/ innovation/ government
5	244	227	library/ information science/ librarian/ cost

In terms of research areas, we identified these subdomains as: (1) evaluative bibliometrics; (2) research performance, in particular collaboration; (3) information retrieval; (4) science and technology (S&T) policy studies, and (5) library science and management. Four of these five subdomains show an increase of activity in absolute numbers from 1992 to 1997. We present the map of SIB (based on the data of 1995-1997) in Figure 10-1.



The circle surfaces indicate the relative number of publication represented by a subdomains. The colors indicate the activity trend during the period 1992-1997 per subdomain: black indicates a strong increase; white indicates a strong decrease of activity. The calculated explained variance is 1.00.

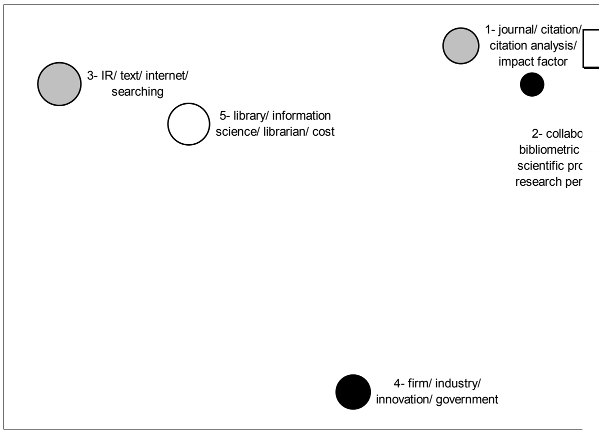
Figure 10-1 Map of SIB 1995-1997

The map shows the close relatedness of 1 and 2 on the right hand side, and of 3 and 5 on the left hand side. Subdomain 4 (S&T policy studies) is found distant from all other four subdomains at the bottom of the map. The main difference between the latter and the four other seems to be the use of data. As all other four subdomains use publication data for their research, subdomain 4 makes use of other data sources (patent data; OECD statistics; survey data) as the research in this subdomains more society/industry-related. The difference between 1 and 2 on the one hand, and 3 and 5 on the other is also obvious. In the former we are dealing with the evaluative bibliometric research, and in the latter with the research related to libraries.

As research is so significantly different in at least three areas of the map, it is to be expected that the information within the subdomains differs as well. To explore this, we implemented a map interface. This interactive tool enables a user to view by subdomain the general statistics concerning actors (countries, authors, etc.), reference statistics (most cited references, most cited institutes), and internal structure (co-word network map of most frequently used keywords). In Figure 10-2, a computer screen shot of the interface is presented.

Delin | Country | All Cs | Authors | Gen Stats | Crefs | Cited Inst

Map of SIB



Highly cited refs in 2 (Collaboration)

92/94	95/97	Cited Reference
1	12	LUUKKONEN T, 1992, V17, P101, SCI TECHNOL
5	7	BEAVER DD, 1979, V1, P133, SCIENTOMETRICS
1	7	OKUBO Y, 1992, V25, P321, SCIENTOMETRICS
8	6	BEAVER DD, 1978, V1, P65, SCIENTOMETRICS
5	6	FRAME JD, 1979, V9, P481, SOC STUD SCI
5	6	SCHUBERT A, 1989, V16, P3, SCIENTOMETRICS
5	6	SCHUBERT A, 1990, V19, P3, SCIENTOMETRICS
2	6	PAO ML, 1992, V28, P99, INFORM PROCESS MANAG

Figure 10-2 Screenshot of mapping interface

This map interface enables a user to evaluate most easily, the internal intrinsic validity (c.f., Figure 3-2) of the generated map. By selecting an information item by clicking one of the top buttons, the top rankings of each subdomain can be retrieved. As the information behind the publications representing each subdomain is directly available, a user does not have to go through piles of papers in order to find the information needed to evaluate the structure. For instance, although subdomain 1 and 2 seem to be covering similar research topics (and therefore they are in each other's vicinity), the lists of most cited references, show significant differences. In subdomain 1 (evaluative bibliometrics) older work from *Garfield*, *Narin*, and *Cronin* is on top, together with more recent work from *Baird*. In subdomain 2 (collaboration), recent work from *Luukkonen* and *Okubo* and older work from *DeBeaver* is on top.

Furthermore, the aggregation by institution of cited references within a citation window of three years, shows both in subdomain 1 and 2, *Leiden University* and the *Library of the Hungarian Academy of Science* on top, accompanied in subdomain 1 by the *University of Strathclyde* and *Indiana University*. In subdomain 2 however, two Scandinavian (*Inst Studies Research & Higher Education*, Oslo; and *Umea University*) and two French institutes (*Ecole Cent Paris*; and *CNRS Paris*) accompany *Budapest* and *Leiden*.

Finally, the structure can be studied in more detail by the subdomain maps. Following the same procedures as the general overview map, we created detailed maps of each subdomain. Per subdomain we identified the most prominent (subdomain) keywords and normalized their co-occurrence to a matrix of cognitive similarity. On the basis of each subdomain matrix, we generated subdomain (network) maps. For all subdomain keywords, we provided the online version with titles of publications covered. Thus, the user is able to 'descend' to the smallest building block of the map, the publication.

As an example, we present the detail map of subdomain 2 (collaboration) in Appendix A. In this map, the most frequent keywords are positioned in a two dimensional space, where words with a similar cognitive profile (co-occurrences with other words) are in each others vicinity. Moreover, the map is enhanced with the identified cluster structure and with connecting lines indicating a strong co-occurrence relation between two individual words. In a second version of the subdomain map the activity trends around the keywords is indicated.

10.3 Expert input

Although many visitors have browsed through the SIB landscape and its additional information, only a few of them gave comments. Seven SIB researchers took the effort to write comments on the maps and on the additional information through the Internet feedback form (see Appendix B).

The feedback form covered two aspects to which the respondents could give comments. The first refers to the structure as a representation of the field SIB. The second refers to the utility of such maps as a policy-supportive tool. Finally, the respondents could give general comments to the method and results.

The overall opinion of the respondents to the structure was positive. Six of the seven respondents recognized the structure as being a good representation of the field as delineated. The seventh respondent was not sure he recognized the structure, as it seemed too much fragmented to him. Furthermore, six respondents could track down their own research in the map. The seventh commented that his research would be dispersed over more than one subdomain. This is, however, the case with all respondents. The other six located their work in subdomain 1 (evaluative bibliometrics) and in at least one of the others (four times in subdomain 2, two times in 3, and once in subdomain 5). As a result, we may conclude that the structure appears not appropriate to pinpoint researchers work to exactly one area. We doubt however, in view of the purpose of the map, whether it should. Our maps of science should represent research fields. The subdomain should represent meaningful clusters of topics. The fact that respondents combine research in subdomain 1 with research in three other, seems to justify the fragmentation of the structure. Together with the fact that six respondents acknowledged the structure as being a proper representation of the field, the map seems appropriate for our purposes.

With respect to topics not covered by the maps very few were mentioned. There were no missing topics mentioned by more than one respondent. There were, however, some doubts with respect to the reference of the maps to the 'real world'. Two respondents found the subdomain labeling too 'synthetic'/formal. One of the respondents did not understand all the used keywords. Another regretted that a term like 'information science' was not covered by most subdomains, but rather by one. Of course, the latter observation is a consequence of the used method. The *topic* 'information science' is covered by all subdomains but the *term* is used to delineate one subdomain only. Finally, one of the respondents provided a long list of keywords he would have expected. The list consists of two types of keywords. The first type covers keywords that are much too general (c.f., index, address, utility), the second type covers more specific terms which are probably missing because they have too low a frequency. In the next chapter we will suggest an improved keyword selection procedure.

The question about the policy supportive utility yielded very few comments. Two respondents mentioned the dynamics to be useful. A third respondent mentioned the linkage of subdomains to institutes (actors and cited institutions) to be a useful aspect. One respondent admitted that he did not understand the way the dynamics were generated and therefore could not comment on utility. Two respondents expressed their concern about the ability of policy makers to understand the maps as being representations of scientific research. One of the respondents attributed great value to the maps. As a decision maker himself, he saw the structure and its evolution as something he already suspected. He stated that research policy in his institution would be influenced by the conclusion that could be drawn from our study.

In this chapter we presented the science mapping method, as it is has been applied by CWTS in the past few years, based on our experiences in the Part II studies. We applied the method to our own research field hoping to attract experts more easily to evaluate the results. The comments revealed that, on the whole, the method yielded acceptable results. Moreover, the (interactive) presentation appeared to be a useful improvement. However, the selection procedure for keywords describing the core of the field needs to be revised.

References

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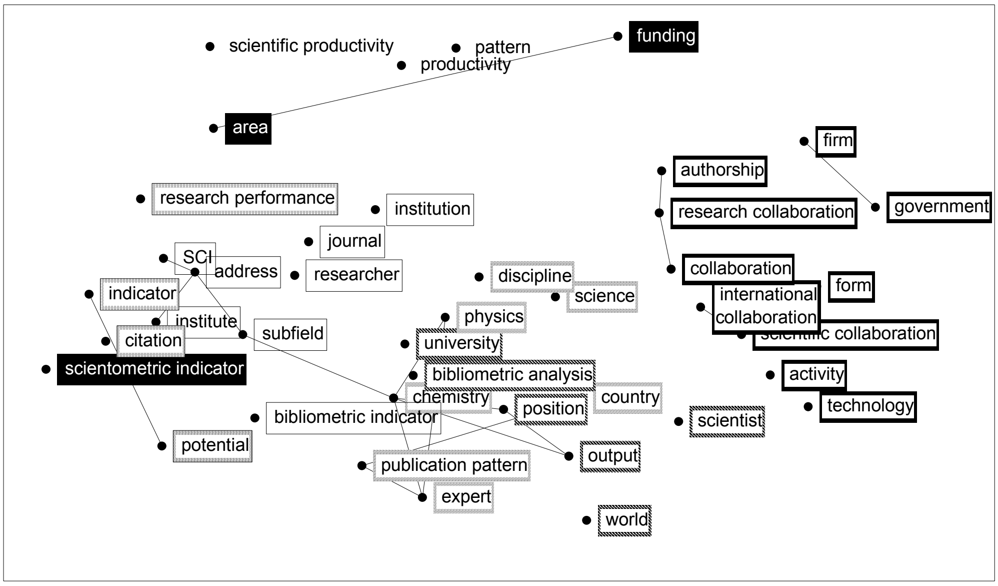
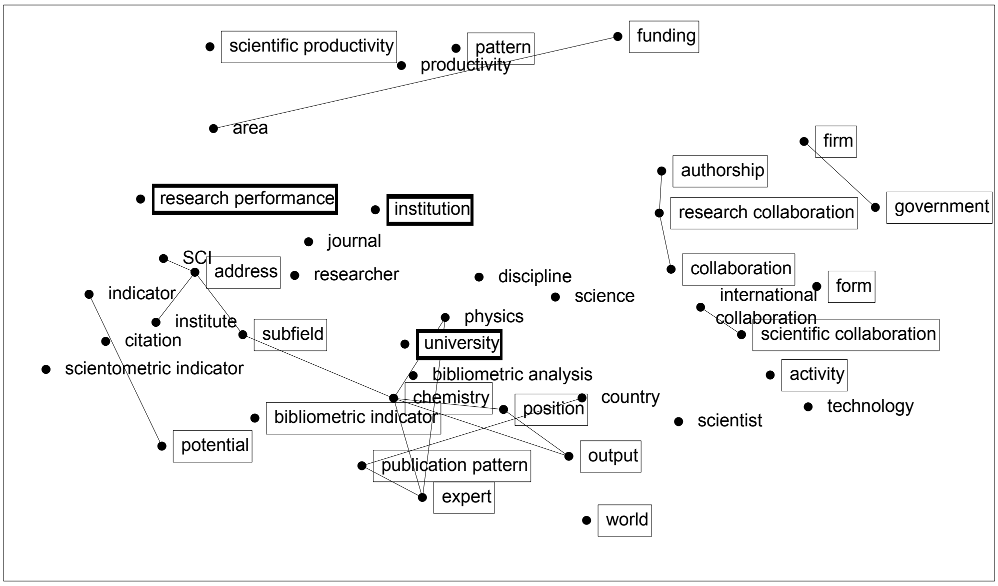
SAS Institute Inc. (1989) *SAS/STAT User's Guide*, Version 6, Volume 1. SAS Institute Inc., Cary, NC, USA, ISBN: 1-55544-376-1

White, H.D. and K.W. McCain (1998). Visualizing a Discipline: An Author Co-citation Analysis of Information Science, 1972-1995. *Journal of the American Society for Information Science* 49. 327-355.

Appendix A



A version



B version

Detail map of subdomain 2 (collaboration) in 1995-1997

Keyword co-occurrence map. Distances based on the cosine co-occurrence vector. The A version of the map is enhanced with the cluster structure (shaded datapoint labels), and with connecting lines between strongly related pairs of individual words. In the B version the keywords with an increasing activity are indicated (label boxes) and those with a decreasing interest (black boxes) during 1992 to 1997. The calculated explained variance is 0.82. Stress: 0.25.

Appendix B

Feedback form of SIB project

Recognizing the landscape

1. Do you recognize the landscape? Does the structure refer to your perception of the field SIB (as defined by the eleven journals)?
   - ○ Yes
   - ○ No
   - ○ Not sure

2. Can you locate your work in one or two sub-domains in the map?
   - ○ No
   - ○ Yes, namely:
     1. ☐ journal/ citation/ citation analysis/ impact factor
     2. ☐ collaboration/ bibliometric analysis/ scientific productivity/ research performance
     3. ☐ IR/ text/ internet/ searching
     4. ☐ firm/ industry/ innovation/ government
     5. ☐ library/ information science/ librarian/ cost

Comments:
…………………………………………………………………….

3. Do you know of areas of interest of the past few years that are represented neither in the overview map nor in any sub-domain map?

…………………………………………………………………….

General Comments

1. Did you come across unexpected structures and/or other findings? And if so: does this refresh your impressions of the field or does it undermine the validity of the maps?

…………………………………………………………………….

2. Did you find any result that could be of importance for policy decisions regarding SIB research? In other words: can you (virtually) think of a situation in which a particular political decision could benefit from the results in these maps that would not have been visualized by a traditional presentation (tables etc).

…………………………………………………………………….

3. Do you have any other comment or question regarding the maps as a tool for policy support?

…………………………………………………………………….

11 Towards automated field keyword identification

11.1 Introduction

In the SIB project, experts have been consulted to make a proper selection of publications to cover the field. Moreover, they could give their comments to the results during the study and afterwards (see previous section). More than once, they have expressed their concern about the selection of keywords and (thus) about the coverage of research in the maps. Not surprisingly, the choice of keywords to create both the overview map and the subdomain maps is of vital importance. Expert consultation during the process of creating the field structure revealed the difficulty in making a proper selection. Simply presenting a list of 'candidate keywords' does not work. Even though we were dealing with bibliometricians, contradictory input was given[24]. In some cases this may be due to ambiguity of candidate keywords.

In this section, a procedure for pre-selection of candidate keywords is proposed. This pre-selection aims at providing the expert with information to help him to make a more well-grounded decision to select or reject a candidate. The setup for such a procedure is based on three principles:

1. The structure (clusters of words or terms) to be generated, should be recognized by researchers in the field or other users of the maps (Section 3.2);
2. The interference of the creator of the map should be limited to a minimum or, ideally, be zero (the objectivity principle);
3. The words used to create a structure should be extractable from any 'standard' bibliographic database (Chapter 2).

The first principle covers the utility of the maps. When the map user recognizes the generated map as a reasonable representation of the field, not only his or her willingness to co-operate will be higher, also the interpretability of the maps will be benefited. As pointed out in Chapter 2, a structure is particularly useful when changes of the structure (in time) can be studied. However, the changes of a structure can only be interpreted if at least *one* situation in the evolution (one picture in the film) is recognized.

The second principle is mainly pragmatic in nature. Complete dependence on field experts is unwanted. It is difficult to find experts who are objective and willing to evaluate the maps and additional information (Chapter 3). Partly because they lack

[24] The keyword *mapping* seems a relevant candidate. In 1998 however, a report from the Welcome Trust was published entitled: 'Mapping the Landscape' in which not even *one* science map is found. The word *mapping* refers, apparently, to a much broader activity than *science mapping* in the 'cartographic' sense, although in bibliometric research it refers indeed in most cases to *cartography*.

time, and partly because they are not acquainted with the method. Moreover, reasonable objectivity is assured if the maps are generated using as little as possible 'human interference'. This objectivity is an important reason for the success of bibliometric methods as an evaluative tool.

The third principle refers to the applicability of bibliometric mapping. As pointed out in Chapter 2, the structure depends partly on the bibliographic database chosen to map the field. In order to be independent from the database producer, the content descriptive elements (CDEs) should be extractable from any 'standard' bibliographic database. A database producer often adds elements to a bibliographic item in order to improve the retrievability (classification codes; indexed terms). These elements improve the recall and precision of a user's search. However, in most cases they are database-specific, so that a map based on these elements, reveals a database-specific structure, rather than a structure based on the research output itself. Moreover, the usage of these database-specific elements preclude the creation of a map based on documents from more than one database. If a study requires that a research field can only be mapped on the basis of publications from several databases, this may become a serious drawback. Particularly in the case of database-specific classification, concordance with other systems can be very problematic.

11.2 From CDE to field keyword (FKW)

Under the assumption that we wish to create a science map based on keywords, there are several bibliographic fields that can be used to extract appropriate FKWs from the publication database representing the field under study. The most important ones are:

- controlled terms (indexed);
- (names of) classification codes;
- titles;
- abstracts.

Consideration of the third principle mentioned in the foregoing section, puts forward *titles* and *abstracts* as the most important elements to be used. Both aim at disclosing the contents of an article, and they are available in most bibliographic databases. Moreover, as they are usually drawn up by the authors themselves, a bibliometric mapping analysis based on titles and abstracts, sticks as close as possible to the original data. A drawback of using these 'free' text elements is the lack of a standardized style and the jargon used by the authors in a field. The first principle suggests that controlled vocabulary and indexed terms are more appropriate CDEs to create science maps. Field experts are more likely to recognize keywords from an indexed list, being generated by other experts. Free terms may not be recognized due to an alternative word choice by authors. Also, the second principle appears to be in favor of the indexed terms. The lack of standardized jargon in any field affirms the need for a controlled vocabulary. It should be noted however that expert interference has already taken place on indexed terms. This is one of the main reasons why indexed terms are not to be preferred, in particular where studies based on multiple bibliographic databases are concerned.

As the use of a 'controlled' CDE encounters principle objections, and the use of a 'free text' CDE only makes the selection procedure more complicated, we explore the feasibility of using the latter to select the relevant FKWs to create the maps. The issue concerning the recognition of the controlled terms as opposed to free text terms is merely challenging towards the use of free text. The arguments against the usage of controlled terms are more fundamental by nature. An *indexed* (controlled) term is per se database-dependent and therefore more subjective. A bibliometric mapping study based on *free* text terms may be conducted with any publication corpus provided by researchers *themselves* in a specific field, as long as titles and abstracts are available.

The selection of keywords to describe the main contents of a publication document starts with *title* and *abstract*. They are elements describing the publication but are too specific[25] for describing the core activities in the science field to which the publication belongs. The 'candidate keywords' should therefore be meaningful parts *from* titles and abstracts. The smallest independently meaningful element in a title or abstract is one single *word*. The most common method used in the early years of co-word analysis based on 'free text', and still used in the present, can be described as follows. From publication titles and abstracts all individual words are identified[26]. Highly frequent, redundant words like *the*, *and*, *can* etc. are removed by using a 'stop word list'. Subsequently, the list of most frequent words is cleaned by removing further 'non-specific' words, such as *case*, *study* etc. The list of remaining words is input for co-word analysis.

To this method two important objections can be raised. First, the usage of 'stop word lists' and lists of 'too general words' requires the input of a field expert. This expert is prompted with relatively much (in his view) redundant information. Expert input should be reduced to a minimum and focused at the most relevant issues. Second, single words cause too much ambiguity. For this reason a word may be excluded from the list of candidates. For example, in the SIB project the word *performance* is a relevant and even central topic. Experts acknowledge this, but for various reasons. For researchers in information retrieval (IR) this word refers to the performance of the *computer* or *software* (speed and quality of results). But in science studies, it refers to the performance of *scientists* (scientific production and impact). A co-word clustering analysis of a set of core terms including *performance*, will probably put these different kinds of research topics together into an 'artificial' cluster.

[25] A publication (including title and abstract) is a unique contribution to the scientific dispute.
[26] Common word boundaries are spaces, hyphens, comma's and dots.

The above observations point out that a co-word analysis should at least allow *phrases* (word combinations, e.g., *research performance* and *system performance*) to join in. As a result a candidate keyword used to generate a science field structure and its representation by a map may be a word or phrase. We consider therefore as the smallest independently meaningful element in a title or abstract, a *word* or a *phrase*. But as long as a phrase is no more than a group of words (within a sentence), it should be determined what kind of phrases *should* and what *should not* be included. On the one hand, identifying any group of adjacent words (see Zamir and Etzioni, 1998) may cause severe interpretation or processing problems if the number of elements within a phrase is only limited by the number of words within a sentence. In that case any sequence of *n* words (n>1) within a sentence is a possible phrase. On the other hand, limiting the number of elements within a phrase to an absolute number may lead to interpretation problems (c.f., *journal impact factor*, would lead to *journal*, and *impact factor* or *journal impact* and *factor* if the maximum words in a phrase would be 2).

Thus far, two main issues involved in selecting the proper keywords to generate a science map were identified: (1) bibliometric distribution (number of occurrences in publications), and (2) semantic scope (exclusion of non-specific words, and specificity of phrases as opposed to single words). At this point a third characteristic of words and phrases is introduced: syntactic, or in a broader sense, linguistic properties (for instance, lexical category of words). This is particularly useful where the identification of phrases is concerned.

In the remainder of this chapter, the setup of the procedure to select 'appropriate' field keywords (FKWs) is discussed using these three characteristics of words and phrases:

- linguistic properties;
- semantic scope; and
- bibliometric distribution.

On the basis of the SIB study data, a procedure is proposed. Next, discussions with field experts in the SIB project and with a field expert in a project for the European Commission on neuroscience are used to validate the procedure in its basic elements. Rather than presenting a completed study, this section outlines a direction for future research.

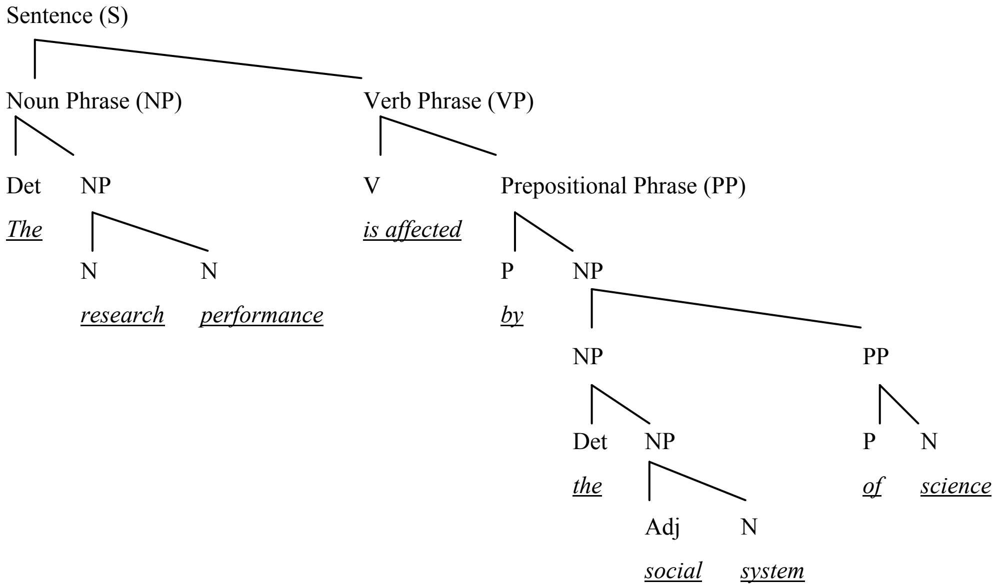
11.3 Linguistic characteristics

The linguistic analysis of titles and abstracts precludes the need for extensive lists of stop words (i.e., words that are to be excluded). These lists contain words like *the*, *and*, and *very*. These unwanted words are more easily detected by determining their lexical category (determiners, modifiers). The morphological and lexical part of a linguistic analysis can easily mark such words.

Moreover, a lot of words in a sentence can be ruled out because of their syntactic characteristics. Adjectives *as such*, for instance, very rarely contribute to the main issues in an abstract of an article. The same holds true for verbs. Consider the following sentence.

> "The research performance is affected by the social system of science"

The syntactic structure of this sentence may be described as follows:



As discussed above, an adjective like *social* as such is evidently not a favorable candidate to describe the article in which this sentence appears. But in the context *social system of science*, the relevance of the word becomes immediately obvious. The syntactic structure identifies the noun phrases *social system* and *social system of science* as coherent, and thus meaningful word-combinations, or phrases. Therefore, these phrases *are* relevant candidates. On top of that, this syntactic structure provides an excellent starting-point to identify phrases within sentences. By using the syntactic structure, we reduce the number of possible phrases within a sentence significantly. Moreover, phrases will more easily be interpreted. The smallest meaningful elements within a sentence should therefore be words and *syntactic* phrases.

Finally, it has been argued that *nouns* are particularly interesting for describing the main contents of an article. In an ESPRIT project in the early nineties (Karlsson, 1990; Karlsson et al., 1995; Voutilainen, 1993), a software tool was developed to extract noun phrases from English sentences. This tool was developed to be used for automated indexing for information retrieval. It has been argued that the noun phrase (NP) plays an important role to identify the main issues of an article. This is supported by the finding that between 80 and 95 of the terms listed in thesauri, or indexed lists of bibliographic databases, are nouns or noun phrases (Arppe, 1995). For our purposes we use a slightly adjusted version of the application developed in the ESPRIT project (NPtool). This NP extracting tool has an excellent performance (Bennet et al., 1997). It is grammar rule-based rather than being lexically-based. The flow chart below describes the process from text to NPs.

Preprocessing
⇓
Morphological analysis
⇓
Constraint Grammar parsing
⇓ ⇓
NP-hostile finite state parsing | NP-friendly finite state parsing
⇓ ⇓
NP extraction | NP extraction
⇓ ⇓
Intersection of noun phrase sets

Source: Voutilainen (1993)

Figure 11-1 NPtool system flowchart

The results of an analysis by NPtool on two selected titles plus abstracts, given in Table 11–1 and Table 11–2. In the texts, noun phrases (NP's) identified by NPtool are underlined.

Table 11–1 Example of a parsed title and abstract of an article (sample 1)

An experiment in science mapping for research planning

This paper considers the recent attempt of the UK Advisory Board for Research Councils to test the usefulness of various citation, co-citation and co-word bibliographic analysis techniques for evaluating the state of various scientific disciplines, including potential areas for useful investment; and in general as an aid to research planning by science policy-makers in a period of steady (or even relatively declining) resources. Results of a study involving the examination of five important scientific fields are considered, and discussion focuses on the advantages and disadvantages of each technique.

(text from: Healey, Rothman, and Hoch, 1986)

Table 11–2 Example of a parsed title and abstract of an article (sample 2)

Where is science going?

Do researchers produce scientific and technical knowledge differently than they did ten years ago? What will scientific research look like ten years from now? Addressing such questions means looking at science from a dynamic system perspective. Two recent books about the social system of science, by Ziman and by Gibbons, Limoges, Nowotny, Schwartzman, Scott, and Trow, accept this challenge and argue that the research enterprise is changing. This article uses bibliometric data to examine the extent and nature of changes identified by these authors, taking as an example British research. We use their theoretical frameworks to investigate five characteristics of research said to be increasingly persuasive – namely, application, interdisciplinarity, networking, internationalization, and concentration of resources. Results indicate that research may be becoming more interdisciplinary and that research is increasingly conducted more in networks, both domestic and international; but the data are more ambiguous regarding application and concentration.

(text from: Hicks and Katz, 1996)

Table 11–3 Comparison of sample 1 and sample 2

Indicator	*Sample 1*	*Sample 2*
Number of sentences	3	6
Number of words in document	96	152
Number of identified NPs	34	41
NP density (ratio NP to total number of words)	0.35	0.27
Number of words covered by NPs	48	57
Average number of words per NP	1.41	1.39
Number of words not covered by NPs	47 (49)	92 (61)

The results in terms of NP's identified by the automated parser are not perfect. For instance, in the last sentence of Table 11–2, the NP *ambiguous regarding application* has been identified. On semantic grounds, only *application* should be identified. On syntactical grounds, however, the NP is correct (c.f., *serious looking woman*). In spite of such 'failures', we use the identified NP's without correcting them. The above described inaccuracy is rare and does not affect the overall quality of the tool. In Table 11–3, some simple statistics of the parsed titles and abstracts are presented.

Evidently, the style of these two abstracts is very different. Sample 1 is rather technical and short, whereas sample 2 is longer and more comprehensible. Apart from such common (quantitative) style characteristics (number of words per sentence or use of passive voice), the difference seems to be indicated by (other) statistics in Table 11–3. With the average number of words within an NP being equal (around 1.4), the number of NPs per document differs (0.35 in sample 1 vs. 0.27 in sample 2). As a result, the ratio of non-NP words to the total number of words in sample 2 is higher (0.61 in sample 2 vs. 0.49 in sample 1).

In spite of the different abstracting styles, the NP extraction tool identifies for both samples a reasonable number of relevant NP's which can be used to describe the contents of each article. Moreover, the words not covered by the NP tool are equally non-informative, and would normally appear in a 'stop word' list, containing words to be removed from the list of most frequently used words by authors in their titles and abstracts (see section 11.1). Seemingly, the NP extraction tool is capable of providing a set of publication keyword (PKW) candidates (Table 11–4).

Table 11–4 Most relevant publication keywords from sample 1 and sample 2

Sample 1	*Sample 2*
Bibliographic analysis technique	application
co-citation	bibliometric data
co-word	British research
mapping	concentration
research planning	dynamic system perspective
science policy-maker	interdisciplinarity
UK	internationalization
Useful investment	networking
Various scientific discipline	research enterprise
	scientific and technical knowledge
	scientific research
	social system
	theoretical framework

In this case, with just two abstracts, it was possible to select these keywords by reading the titles and abstracts and than checking the list of candidates 'manually'. But obviously, in bibliometric studies involving many thousands or sometimes even hundreds of thousands of publications, this is undoable. Therefore, a powerful and fast algorithm is absolutely needed to select these words automatically. To meet this strict requirement, we need more information about the semantic context of the candidates.

Obviously, the opinion of a field expert is crucial for this issue. In the case of SIB – our own field of research - we were able to make the selections ourselves. But generally, we depend on an 'external' field expert. As pointed out in Chapter 3, the way in which the data are presented to the expert will influence the quality of the results. If an expert is prompted with every possible keyword and is kindly asked to give his opinion, you may end up with no input at all. If there has been a considerable pre-selection, results will be more to the point. In the next section, a new procedure will be proposed in which this pre-selection reduces the work for the expert significantly. As these pre-selections are based on objective criteria, and as the expert will be informed about them, the discussion will be focused on the relevant issues.

11.4 Semantic scope

The primary **meaning** of a word or phrase has at least three levels:

A. Meaning as such (in a dictionary: more or less general);

B. Meaning within a field (specific, 'field jargon');

C. Meaning within the article (contextual, sometimes even metaphoric).

In the process of selecting FKWs, all these levels must be taken into consideration. The following example will illustrate these levels and their contribution to the selection procedure.

Table 11–5 Meaning overview of a noun phrase sample

Candidate keyword: Impact

Context level		*Meaning*	
A	Dictionary	*Noun*:	hit, influence
		Verb:	implant, hit
B	Noun within field (SIB)	1.	Citations per publication
		2.	Scientific influence
C	Noun (citation per publication) within article (function within discussion)	*Result*:	(…) that the impact of institute X is below the impact of Y (…)
		Method:	(…) using the ISI impact factor (…)
		Object:	(…) creating a new impact factor (…)
		Neutral:	(…) that this does not have any impact on the usage of (…)

First, the word *impact* appears in two lexical categories: noun and verb. The meaning in both is related. As a noun, it has a both a *physical* and a *mental* connotation (A level). In the scientific field of SIB and related fields, *impact* has a general meaning *and* a specific meaning (B level). The impact of publications is measured by the number of times it is cited. The bottom line is: the more often an article (or person) is cited, the more impact it has (on other researchers). Moreover, the function within the article (C level) can be of importance when examining candidate FKWs to generate a field structure.

In the above configuration, we identify three different context levels in which the candidate has its 'meaning'.

- The A level, which is the 'whole world' or, at least, the world of science;
- the B level, which is the 'world' of the science field (for instance SIB);
- the C level, which is the very limited 'world' of the article, so that 'meaning' should rather be described as 'function'.

In view of the objective of this chapter, the B level plays a crucial role, as we are trying to identify *field keywords* rather than *publication keywords* (PKW, c.f., Chapter 2) or *science keywords*. If a word primarily has its meaning on this B level, it will be a relevant candidate to be used to structure the field. If candidate primarily has its meaning on the A level, it is most probably removed from the list on the basis of being non-field specific. In the samples (Table 11–1 and Table 11–2), words such as *article, author* and *data* are examples of such non-specific words. The meaning the C level seems too specific in order to be used for the objective. Is the 'meaning' or 'function' of *impact* within the article of any relevance to structure the field of SIB? In particular cases, where the structure has a certain purpose, this may be the case. Leydesdorff (1997) pointed out that particular words may appear in the introduction, method, results, or conclusions section. He argues that this particular phenomenon proves that words should not be used to map (the dynamics of) science. In his reply, Courtial (1998) argues that this wandering in particular is in favor of co-word analysis as a tool to visualize the dynamics of science. The shift of a topic from one section to another will cause changes in the word co-occurrence data. These changes reflect the developments in the particular science field. As long as the data are robust enough, the results will not suffer from inadequacies due to sociolectic and jargon matters. So, in studies where mapping concerns the visualization of the field dynamics, this 'function' issue does not seem to create a problem, because the aim is to generate a map on the B level, not on the C level.

Still, there is an important aspect about the C level. In relation to this aspect, Leydesdorff (1989) did a significant observation. It concerned the applicability of title words on the one hand, and abstract words on the other, for co-word maps. Leydesdorff (1989) reached the conclusion from a biochemistry publication corpus, that on average abstract words are *less specific* than title words. That is, the selection of most frequent abstract words was less specific than the selection of most frequent title words. But Peters and Van Raan (1993a) reach the opposite conclusion, comparing the title co-word map with the abstract co-word map.

> Comparing the maps, we see that in many places the same words are visible (…) Furthermore, title words cover more general words than abstract-words, such as "chemical", "experiment-", "measurem-", or "using". Thus, title-words appear to be somewhat more general in scope, but differences are not as clear-cut as found in the study of Whittaker (1989).
>
> (Peters and Van Raan 1993a, p. 31)

In their study, however, Peters and Van Raan used the uncontrolled terms of the Chemical Abstracts database. These uncontrolled terms are keywords directly extracted from abstracts and not unified or indexed. In that sense, they are similar to the keywords that Whittaker (1989) compared to title words. In both studies *not all* abstract words have been considered, but both seem do have used *all* title words. Peters and Van Raan found the word "using" as one of the most frequent title words but not as a (abstract) keyword. The reason for this is, of course, that this word already has been filtered out by the database producer as being too general to be a (abstract) keyword. Leydesdorff (1989) filtered out the same (stop) words from titles and abstracts and *then* compared the specificity of the most frequent ones. In that sense, it is understandable that Peters and Van Raan find that title words are more general, whereas Leydesdorff (1989) found the opposite.

The title is both an advertisement-board of the article and, in most cases, the shortest possible descriptor of its contents (Whittaker, 1989). These two objectives of a publication title, require that it refers to the context either on the C level (description) or on the B level. Generally speaking, the audience addressed in scientific journals is from the B context and should be able to read the main issues addressed in the article from the title. Together with the descriptive requirement, this accounts for the specific character of title NP's. The fact that the most frequent NP's in abstracts are less specific than title NP's is primarily due to the requirement that the readability (as the knowledge of language goes beyond the B context, it refers to the A context) of abstracts should be higher than the readability of titles[27]. In the project SIB, reported in section 10 of this chapter, we generated some general statistics concerning the NP usage in titles and abstracts (Table 11–6).

Table 11–6 General statistics of NP's in SIB abstracts (1992-1997)

Indicator	*Titles*	*Abstracts*
Total number of publications	2,503	2,503
Average number of NP's	3.95	29.66
Average number of words	10.42	113.61
Average NP density	0.39	0.27
Average number of words per NP	1.87	1.68

These figures show that, on average, four NP's are included in titles and almost thirty in abstracts. The average NP density (ratio NP to the total number of words) of titles is significantly higher (0.39 vs. 0.27). The latter observation supports the finding in Leydesdorff (1989). The specificity of title words is much higher because, on average, less non-informative words are involved. Furthermore, these overall statistics in SIB show that the NP density of the abstract in Table 11–1 (sample 1: 0.35) almost reaches a title average of 0.39. The absence of 'non-informative' words in this abstracts does not improve its readability.

[27] In most cases the title is not a sentence but rather an elliptic phrase 'mapping the field of SIB' rather than 'In this article we will give a report of the study concerning the mapping of the field of SIB'.

This observation indicates that the title seems more appropriate to extract the most specific keywords from the candidates than the abstracts. The second sample, however, shows that the title is useless for that matter. The latter title is primarily used to attract readers, rather than to cover the main issues addressed (see Whittaker, 1989 and Peters and Van Raan, 1993a). A selection of most specific keywords per document (PKW) exclusively based on their occurrence in title (or abstract) does not seem reasonable.

11.5 Bibliometric distribution

An overview structure of a field based on keyword co-occurrence, requires that the most central keywords are used. Bibliometrically speaking this means that the most frequent keywords are used. In previous sections, it has been argued that the selection of nouns (NPs) may be a good pre-selection. Moreover, it has been argued that on average the NP in a title yields more specific information about the contents of an article than the abstract. As a result, we argue that most frequently used NP's in abstracts tend to be less specific. All kinds of 'common' methods, data and tools are being discussed in abstracts. These methods and tools are of great importance for the development in a research field, but do not contribute per se to the identification of core topics and areas in a field. Moreover, it has been argued previously that the readability requirement plays a role in the specificity of the average abstract NP. Thus, we conclude that the distribution of abstract NPs may be of importance to identify PKWs, but it seems not to contribute directly to the identification of FKWs. For the latter the distribution on the B level context is significant. title NPs seem to be more appropriate at this level. Moreover, at this level of aggregation the 'advertisement' titles (c.f., "where is science going?") will not interfere because of their low frequency. For these reasons, we select high frequent NP's for the overview structure from titles only. Then, to create the structure based on the selected FKWs, we use their co-occurrences in both titles *and* abstracts.

11.6 Combining the three aspects

In view of the objective in this chapter, the proposed selection procedure requires the following information about each candidate:

- lexical category;
- syntactic structure;
- distribution in titles within field;
- distribution in abstracts within field;
- distribution within field as opposed to distribution in whole of science.

The lexical category and syntactic structure is needed to select NPs only. The former is to identify the NPs, the latter has appeared recently to be useful regarding the semantic scope of the NPs. After having created a list of relevant candidates for the SIB study and having created a list of NPs to be excluded, we discovered a certain pattern. There appeared to be a clear correlation between complexity of the NP structure (in terms of number of words included) and the likeliness to be selected as being specific enough. The list of NPs to be excluded contained almost exclusively single word NPs (SWNP), whereas the list of selected NPs almost exclusively contained multiple word NPs (MWNP). In a presently performed study for the EC in the field of neuroscience, we encountered a similar finding. On the basis of our findings in SIB, we created a list of MWNPs on the one hand as most likely candidates, and a list of SWNPs with candidates to be excluded on the other. A field expert evaluated both lists. At first, he was rather skeptic about the pre-selection. After having evaluated the two lists, he noted about 10 MWNPs which had better be removed from the list of keyword candidates. Moreover, he selected only 40 words from a list of 500 SWNPs which, in his opinion, should be included in the list of keywords. In some of the latter cases, it concerned SWNPs with a 'complex' morphological structure (e.g., *immunoreactivity*). In these cases, the SWNP is composed of two 'virtually independent' words. As a result, we should consider to regard the morphosyntactic characteristics of an SWNP as well[28].

Two additional findings support the proposed pre-selection. For the NPs identified by NPtool in the samples of Table 11–1 and Table 11–2, we searched in the Social Science Citation Index (SSCI), and within a subset of documents included in the journal set of the SIB study. The SSCI we take as a representation of the 'whole of science'[29] (the context on A level of Table 11–5), the journal subset as a representation of the field (B level). For each identified NP from sample 1 and 2, the ratio of occurrences in B to occurrences in A was calculated ('specificity index'). Furthermore, the NPs were categorized on the basis of their syntactic structure and selection by experts, and for each category an average is calculated (Table 11–7).

[28] Note that the morphological difference between 'immunoreactivity' and 'science policy' does not exist in, for instance, Dutch ('immunoreactiviteit' vs. 'wetenschapsbeleid'). The linguistic treatment of word compounds plays an important role in this discussion and will be taken into consideration in future research.

[29] Of course, it would be more accurate to take the whole set of ISI products to represent the whole science output if not all available scientific output databases. For my point here, the SSCI seemed enough.

Table 11–7 Specificity Indicators for NPs in two SIB samples (Table 11–1 and Table 11–2)

NP type	*Specificity Average*
All NPs in sample 1 and 2	0.06
Single Word NPs	0.02
Multiple Word NPs	0.35
Expert-selected NPs	0.22
Expert-excluded NPs	0.02

The results show that the specificity of both multiple word NPs as opposed to single word NPs, and expert-selected NPs as opposed to non-selected NPs is significantly higher. On the one hand this may indicate the syntactic structure to be a useful source of information to make a pre-selection of candidate NPs. On the other hand, it suggests that the distribution of any candidate NP within the field as opposed to its distribution within the whole of science may indicate its relevance to the field, in terms of representing the core activity of a science field.

Furthermore, we calculated the specificity index for 120 SWNPs from the SIB study. It showed an average value of 0.03, whereas the specificity of MWNPs in SIB revealed 0.21 on average.

Egghe (1999) shows that the rank-frequency distribution of multi word phrases (not *noun* phrases only) is significantly different from the distribution of single word phrases. Referring to Smith and Devine (1985), he indicates that the exponent β of multiword phrases decreases with an increasing number of elements within the phrase. A similar finding is in the graph of Figure 11-2, where the distribution of SWNPs and MWNPs in SIB is shown. It shows a slope of SWNPs that is much steeper than the slope of MWNPs. The head of their distribution (up to rank 100), however, is similar. This phenomenon has to be studied in more detail.

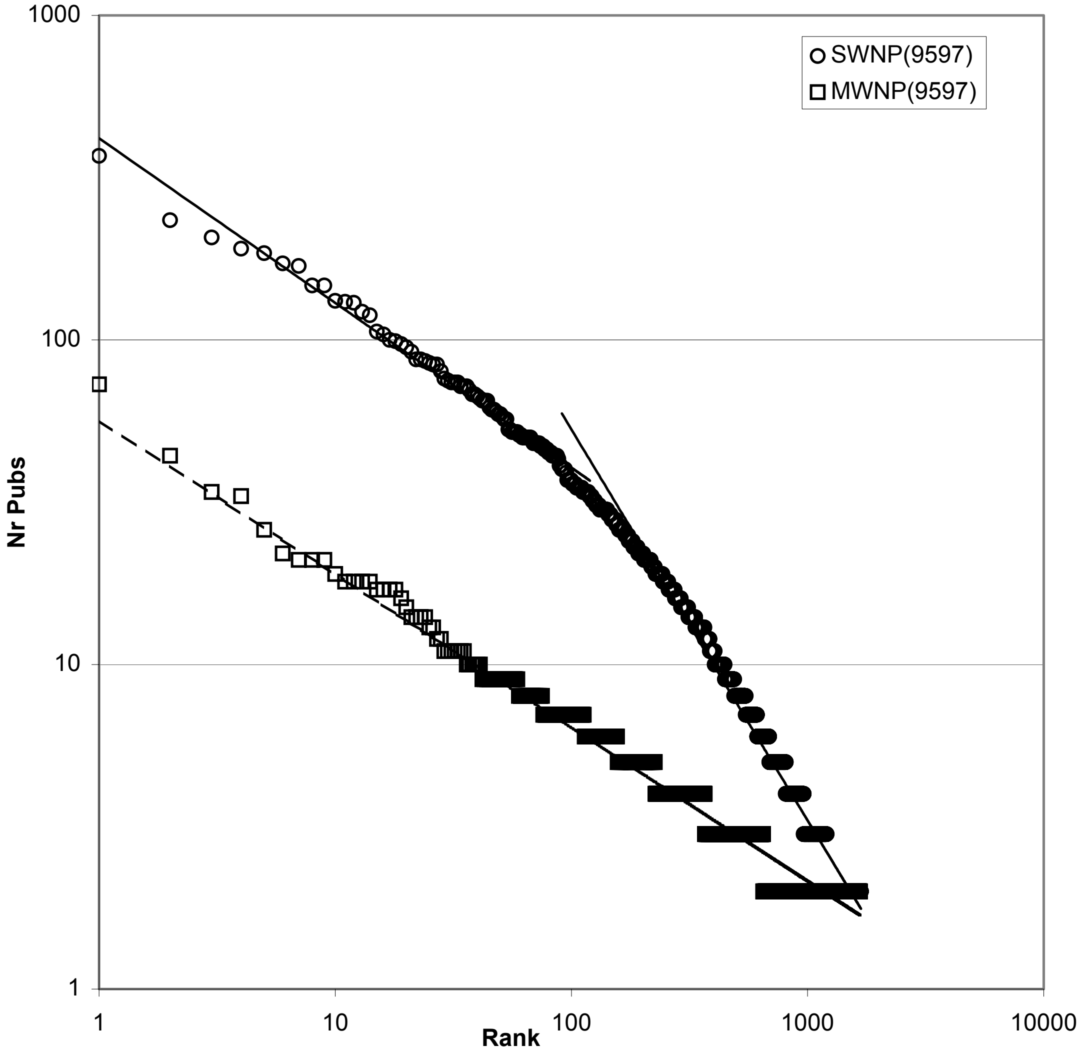


Figure 11-2 Zipf distribution of single word NPs and multiple word NPs in SIB (1995-1997)

On the basis of the above observations a pre-selection of NPs on the basis of their syntactic properties seems justified. Furthermore, in the neuroscience project, we experienced a smooth validation by making certain pre-selections and by providing the expert with well-structured and well-documented information about the candidate keywords. In particular the division of pre-selected keywords (within a generated cluster structure) on the one hand, and the initially rejected NPs on the other, speeded up the procedure considerably. Thus, well-aimed questions could be asked to the expert with regard to the required input. Moreover, by structuring the data, the expert had a kind of preview into the results. A summary of the proposed selection procedure is sketched in Figure 11-3.

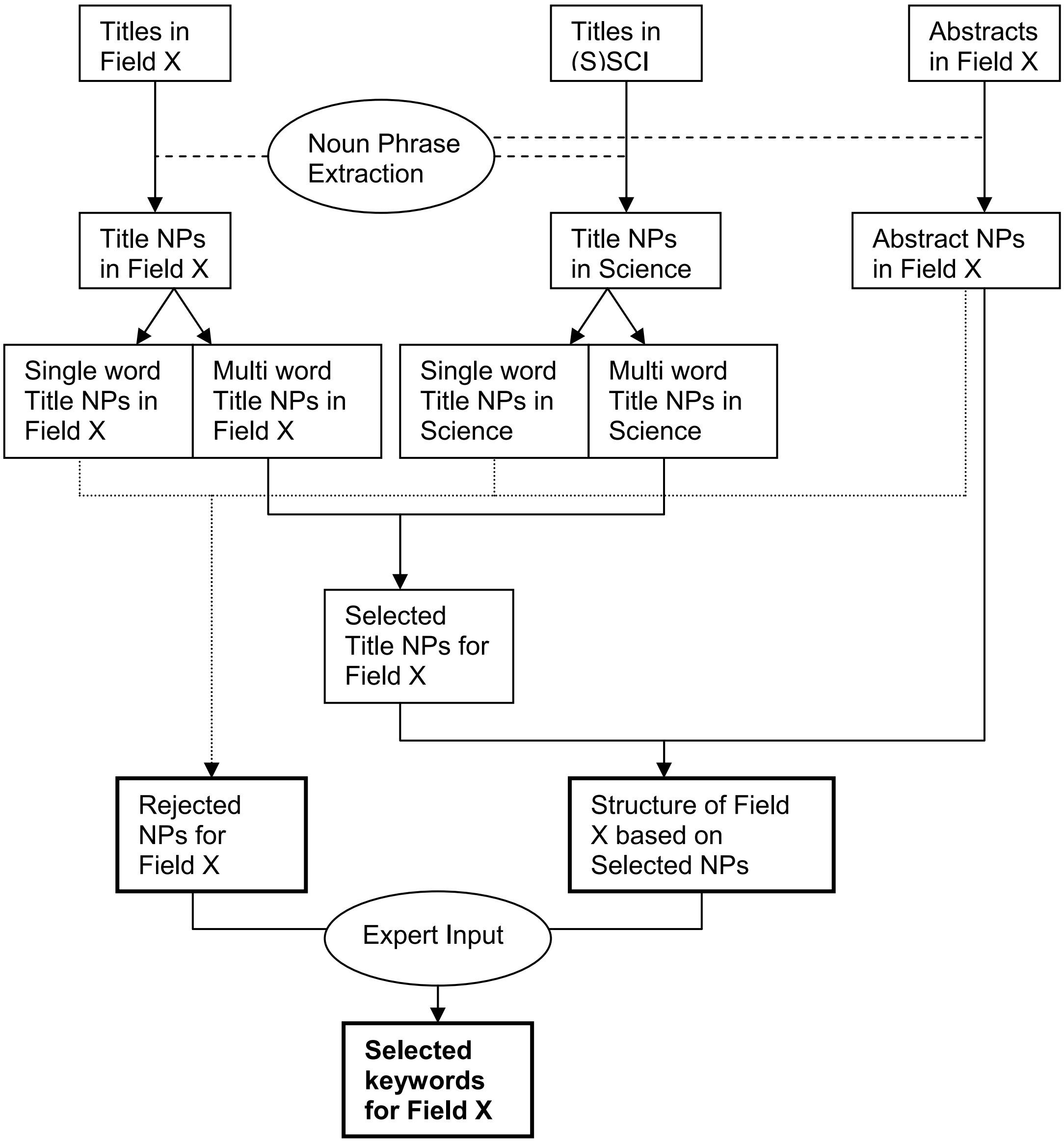


Figure 11-3 Flowchart of the keyword selection procedure

In the procedure, we start with the titles and abstracts from publications representing a particular field *X*. From the titles of these publications, the NPs are identified by linguistic analysis. Of the most frequently used NPs we collect the numbers of hits within the field and within the 'whole of science' (indicated with (S)SCI). As discussed earlier, the ratio for each NP indicates its specificity. Furthermore, the NPs are divided into multiple word NPs and single word NPs. The specificity index of multiple word NPs is used to exclude certain candidates being too less field-specific. From the list *single* word NPs those with a significant specific character are also transferred to the selected candidates. The selected candidates are subject to a co-word clustering analysis. The frequencies of these NPs are retrieved by searching in titles *and* abstracts. The generated structure (keywords assigned to clusters) are proposed to the expert. The list of initially rejected candidates is also presented to the expert.

In this chapter we propose a procedure to select field keywords from a publication database by field experts. The procedure is based on the specific character of title NPs and the combination of several characteristics of words. Moreover, by presenting the lists of keywords in a structured way, we claim that the results will be most valuable.

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12 Conclusions and future perspectives

Science mapping is not yet fully integrated as a bibliometric tool for science policy and research management. As the generated structures based on co-word and co-citation analysis are often hard to interpret, potential users mistrust their utility. The aim of this book is to take a first step to overcome this incomprehensibility and thus to improve their utility.

One of the things that make bibliometric maps hard to understand is the fact that they are constructed in many different ways. They may be based on different bibliographic information elements, such as author names, titles, author addresses, and cited references. Each element renders its own map of the same set of publications, because each element reveals its own aspect of publications. A map based on co-author data reveals primarily the social structure, whereas a co-word, co-classification or co-citation analysis is more likely to reveal a cognitive structure. Nonetheless, each cognitive information element reveals its 'own' structure, which subtly differs from those revealed by other cognitive elements. However interesting, the integration of bibliometric maps is not served by these differences. A cognitive structure 'always' based on one an the same element, contributes to a better understanding because experts and (other) users will become familiar with them and the kind of structure they reveal. In this book it is pointed out that co-word analysis based on titles and abstracts has advantages over co-classification and co-citation.

In this book a method is proposed to extract keywords from publication titles and abstracts, to be used to structure research fields. A combination of linguistic analysis and bibliometric distribution, is used to list candidates, which is to be checked by field experts. In relation to this, the need for expert validation is discussed. At present this input is needed to validate the map as a trustworthy representation of the mapped research field, in order to be used as a policy-supportive tool. A procedure is designed to apply the expert input at an early stage of the mapping analysis. This early stage input prevents 'errors' to occur which would otherwise only be revealed in the final map and precludes 'non-committal' expert comments if the generated map represents the field reasonably well. The early stage input serves the objectivity, whereas the effort of the expert is reduced to a minimum. With the expert validation the reference to 'the real world' is assured, and thus the utility of the map is improved.

From a practical point of view, the accessibility of the map structure is improved by the developed electronic version. All the information 'behind' the map, which is needed to explore and to evaluate it, is readily at hand by 'clicking', in stead of by browsing through massive paper reports.

To improve the applicability of bibliometric maps to science policy and research management, a method is proposed to combine science field dynamics analysis and actor trend analysis. A combination of answers to the questions 'what are the main developments in the field?' and 'what is the role of the actors?' increases the utility of these maps to a great extent.

The work presented in this book should not be considered as a completed trajectory. The proposed improvements to bibliometric mapping as a policy-supportive tool merely introduce the transition to a new generation of science an technology maps. This new generation S&T maps are characterized by their flexibility and interactivity. Hence, they will be fit to be used to address a all kinds of S&T policy-related issues.

First, the maps will be enhanced with more information about the positioning of the items in a science map. A two-dimensional map with n items (for instance, subdomains) represents the n-1 relations of these items. One may wonder whether the position each individual items gets, is trustworthy and whether a changing position of an item from one year to an other really means that its relation with the surrounding items has changed. To investigate this, we are developing a tool to obtain linkage information from an individual item's perspective. This tool enables an expert or (other) user to obtain information about the pairwise relations of each individual item in a map with the others. An overview of these 'one dimensional' relations can be used to validate the position of an item in relation to the others. Moreover by providing this tool at several stages in an field evolution, we enable an expert or user to evaluate and validate the changing structure.

Finally, as initiated in Chapter 9, we are establishing the integration of science mapping on one side and research performance analysis on the other. By this integration, the evaluative bibliometrics will increase its potential use and utility. In Noyons, Moed and Van Raan (1999), this will be discussed in more detail.

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Samenvatting

Dit boek levert een bijdrage aan de ontwikkeling van bibliometrische kaarten als instrument voor wetenschaps- en technologiebeleid. Op de eerste plaats wordt duidelijk gemaakt dat het van cruciaal belang is om de juiste vraag te formuleren die met de kaarten beantwoord moet worden. Verder wordt aannemelijk gemaakt dat expert 'input' (vooralsnog) wenselijk is om de kaarten te valideren. En om die 'input' zo efficient mogelijk te verkrijgen, worden procedures ontwikkeld. Tenslotte wordt een vorm waarin de resultaten worden gepresenteerd voorgesteld, waarmee de bruikbaarheid wordt verhoogd. In die (interactieve) vorm wordt het mogelijk om op eenvoudige wijze een antwoord te krijgen op een gestelde (beleids-) vraag.

Sinds de zeventiger jaren worden wetenschapskaarten op basis van bibliometrische gegevens gebruikt voor beleidsdoeleinden. Er was een behoefte aan overzichten van wetenschapsgebieden en de ontwikkelingen ervan. De bibliometrie, gebaseerd op kwantitatieve analyses van bibliografische gegevens, werd geacht aan die behoefte te voldoen. Immers, wetenschappelijke publicaties kunnen de kennis die is opgebouwd representeren. Een verzameling van alle relevante publicaties moest in staat zijn een zinvolle weergave te leveren van wetenschapsgebieden. Zodoende werd het begrip bibliometrische kaart van de wetenschap geboren. Deze kaart had als voordeel dat hij 'objectief' zou kunnen worden gegenereerd.

Om de betrouwbaarheid en bruikbaarheid van de wetenschapskaarten voor beleidsdoeleinden te verhogen was het echter nodig de kaarten te valideren. Het belang hiervan is evident. Een kaart die uit de gegevens 'rolt' maar op geen enkele wijze refereert aan de 'werkelijkheid' zoals die door gebiedsexperts wordt gezien, kan niet eenvoudig gebruikt worden als beleidsinstrument. Beleidsmakers stellen immers vooralsnog hun vragen vanuit de 'werkelijkheid' zoals die door de experts wordt opgesteld.

In het eerste deel van dit boek wordt een korte beschrijving van de geschiedenis van bibliometrische 'wetenschapskaarten' voor beleidsondersteuning gegeven. Verder worden de principes beschreven waarop deze wetenschapscartografie is gebaseerd. Tenslotte wordt er in hoofdstuk 3 kort ingegaan op de validering van de kaarten. Er worden twee soorten onderscheiden: de validering door de gebiedsexpert, en de validering door de gebruiker. Er wordt voor gepleit om dit onderscheid duidelijk te onderkennen en de input gericht in te zetten.

In het tweede deel van dit boek (hoofdstukken 4 tot en met 9) staan zes artikelen die in het recente verleden gepubliceerd zijn. Ieder van hen draagt op zijn eigen manier bij aan de discussie met betrekking tot wetenschaps- en technologiecartografie als beleidsinstrument. Samen geven zij een overzicht van de ontwikkeling van dit instrument zoals die bij het CWTS heeft plaatsgevonden.

De studie die in hoofdstuk 4 wordt gepresenteerd bevat geen kaarten maar laat zien hoe het valideren van kwantitatieve gegevens kan plaatsvinden met behulp van andere gegevens. Die methode staat bekend als 'internal intrinsic validation' (zie hoofdstuk 3). De structuur van een technologisch gebied (lasers in medische toepassingen), gerepresenteerd door octrooigegevens, werd vastgelegd met betrekking tot de 'wetenschapsintensiteit'. Die intensiteit zou gemeten moeten kunnen worden aan de hand van het aantal verwijzingen naar wetenschappelijke literatuur in octrooien. Deze hypothese werd getest door algemene kararteristieken met betrekking tot wetenschapsintensiteit van de publicaties van de uitvinders van die octrooien. De intensiteit van de publicaties werd vastgesteld op basis van het fundamentele dan wel toegepaste karakter van de tijdschriften waarin ze verschenen. We vonden dat het aantal wetenschappelijke verwijzingen in octrooien samenviel met een relatief hoog 'fundamenteel' karakter van de publicaties door de uitvinders van die octrooien. Verder werd in deze studie de 'structuur' gevalideerd met behulp van expert-gegevens (internal exstrinsic validation).

De eerste versie van de huidige kaarten wordt gepresenteerd in hoofdstuk 5. Het bestudeerde gebied 'optomechatronica' waarin optische, mechanische en elektronische technieken worden gecombineerd, kent een wetenschappelijke en een technologische kant. In deze studie is de eerste poging ondernomen om gegevens van beide zijden (publicatie- en octrooigegevens) te integreren. Door deze integratie kwam direct een 'informatie-gat' aan de octrooikant aan het licht. Een omvangrijk deelgebied van optomechatronica (control/software engineering) dat aan de wetenschappelijke kant werd gevonden, was niet zichtbaar op de octrooikaart. De reden hiervoor is dat software moeilijk octrooieerbaar is onder het Europese octrooirecht. Het feit dat er geen activiteit werd gevonden op de technologiekaart betekent dus niet dat die er ook helemaal niet is. Dit pleit er eens te meer voor om met het oog op de vraag die beantwoord moet worden met de kaart, de juiste keuze van gegevens te maken (zie ook hoofdstuk 2). Bovendien geeft het de noodzaak aan om op zijn minst het gebruik van onderliggende gegevens met experts te bepreken.

Hoofdstuk 6 is met name een methodologisch hoofdstuk waarin de grondbeginselen van de huidige CWTS cartografie worden besproken. In deze studie wordt een methode voorgesteld voor het integreren van enerzijds het in kaart brengen van de evolutie van een gebied en anderzijds het uitvoeren van een betrouwbare actorenanalyse. De eerste is gebaat bij een 'vrije' structuur om de dynamiek tot zijn recht te laten komen. De tweede is juist gebaat bij een vaste structuur om de activiteit van actoren in het ene jaar goed te kunnen vergelijken met die in een ander jaar. De voorgestelde methode biedt voldoende ruimte om beide aspecten te belichten. Verder wordt in deze studie het karteren op meerdere nivo's voorgesteld. Vanaf een gebiedsoverzichtskaart kunnen de verschillende deelgebieden gedetailleerd in kaart gebracht worden. Samen met de beschikbaarheid van gegevens per deelgebied, hebben deze onderdelen de hele wetenschapscartografie als beleidsinstrument aanzienlijk verbeterd.

In hoofdstuk 7 wordt een uitgebreide 'case study' behandeld (neural networks research) die met behulp van de beschreven methode is uitgevoerd. Aan de hand van 'virtuele' beleidsvragen wordt de methode getest.

De studie in hoofdstuk 8 bevat wederom geen kaarten. Het accent ligt hier op de gebiedsafbakening, een cruciaal element bij de bibliometrische cartografie. In opdracht van het Vlaams Ministerie werd het gebied informatietechnologie (IT), en in het bijzonder de Vlaamse verrichtingen, bibliometrisch in kaart gebracht. De stuctuur van IT werd hier gedefinieerd met behulp van gebiedsexperts. Zij bakenden de verschillende (vooraf beschreven) deelgebieden af met classificatie-codes. Zodoende werden publicaties en octrooien over deelgebieden verdeeld. Na de toekenning van classificatie-codes aan de verschillende deelgebieden, kwam men tot de conclusie dat een bepaald deelgebied slecht was vertegenwoordigd met publicaties. In een tweede ronde werd dit deelgebied verder opgetuigd met behulp van classificatie-codes. Uiteindelijk bleek dit *de* speerpunt van de Vlaamse IT. Hoewel we in geen geval de betrouwbaarheid van de experts in twijfel trekken, geeft dit wel aan hoe delicaat de input van experts kan zijn, zeker met betrekking tot uitspraken in de beleidssfeer. Een afbakening en indeling op basis van bibliometrische principes zou in dit geval eerder als 'objectief' kunnen worden beschouwd.

In de studie in hoofdstuk 9 wordt de methode van 'intrinsic internal validation' verder ontwikkeld. In het kort komt het erop neer dat de geïdentificeerde deelgebieden in de micro-elektronica, op basis van samenvoorkomen van classificatie-codes, worden voorzien van 'kaart-externe' informatie. Het betreft hier informatie over de onderliggende publicaties die niet direct betrekking hebben op de gegenereerde structuur. Een voorbeeld zou kunnen zijn: document-types van publicaties. We gaan ervanuit dat in een kaart publicaties met cognitieve overeenkomsten gaan 'clusteren' en dat er in zo'n cognitieve structuur een onderscheid te zien is tussen fundamenteel-geörienteerd en toegepast onderzoek. Dit zou dan moeten zijn terug te vinden in de verdeling van de document-types over de deelgebieden in de kaart. In de toegepaste deelgebieden zal, bijvoorbeeld, het aandeel 'proceedings papers' veel hoger zijn dan in de fundamentele gebieden. In zo'n geval is de document-type informatie kaart-extern, aangezien die kaart is opgebouwd op basis van patronen die classificatie-codes met elkaar hebben, en niet op basis van gegevens over document-type.

Uit de studie in hoofdstuk 9 blijkt dat de toevoeging van kaart-externe gegevens een praktisch probleem met zich meebrengt. Met het oog op validatie en bruikbaarheid is het van belang dat zoveel mogelijk informatie 'achter' de kaart beschikbaar is. Als die informatie echter opgezocht moet worden in een (gedrukt) rapport, besteedt de expert of gebruiker onnodig veel tijd aan bladeren en opzoeken. Daarmee wordt een van de primaire doelen, tijdswinst, niet of nauwelijks gerealiseerd. Gezien de recente ontwikkelingen van grafische interfaces, lag een digitale versie van de kaarten voor de hand. In hoofdstuk 10, aan het begin van deel 3, wordt aan de hand van een studie in het eigen vakgebied (scientometrie, informetrie en bibliometrie) een prototype van zo'n interactieve rapportage gepresenteerd.

In hoofdstuk 11 wordt de methode van de bibliometrische cartografie verder ontwikkeld aan de hand van een procedure-ontwerp om sleutelwoorden van een vakgebied te selecteren. Deze sleutelwoorden zijn essentieel om een gebied cognitief in kaart brengen zonder dat daar 'gevestigde' thesaurus-termen of classificatieschema's van de grote gegevensbanken aan te pas komen. Vooralsnog steunt die procedure nog voor een groot gedeelte op 'input' die experts leveren. Deze kan echter tot een minimum beperkt worden.

Tenslotte geeft hoofdstuk 12, naast de belangrijkste conclusies, nog een aantal aanknopingspunten voor verder onderzoek en ontwikkeling. De belangrijkste conclusie is in ieder geval dat door toepassing van de huidige ontwikkelingen in methoden en technieken, de bibliometrische cartografie een nieuw tijdperk ingaat met betrekking tot ondersteuning van wetenschapsbeleid en planning.

Curriculum Vitae

Everard Christiaan Marie Noyons werd op 10 juni 1963 geboren te Drunen. In 1981 haalde hij het Gymnasium-alpha diploma aan het Jeroen Bosch College te 's-Hertogenbosch. In 1989 werd hij doctorandus in de Nederlands Taal en Letterkunde aan de Universiteit Utrecht, met als hoofdvak Nederlandse Taalkunde. Daarna heeft hij zijn vervangende dienstplicht vervuld bij het Centrum voor Wetenschaps- en Technologie Studies (CWTS), dat toen nog het Leids Instituut voor Beleidsonderzoek, sectie Wetenschapsonderzoek (LISBON-WO) heette. Na die tijd is hij verbonden gebleven aan dat instituut en is zijn aandacht steeds meer verschoven van bibliometrisch evaluatie-onderzoek naar de cartografie van wetenschap en technologie. Vanaf 1995 heeft hij, onder begeleiding van Prof. Dr A.F.J. van Raan, de huidige lijn voor de cartografie ingezet met de nodige publicaties als resultaat en een lijst interactieve rapporten die via Internet te bezoeken zijn.