Bibliometric mapping as a science policy and research management tool

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

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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!

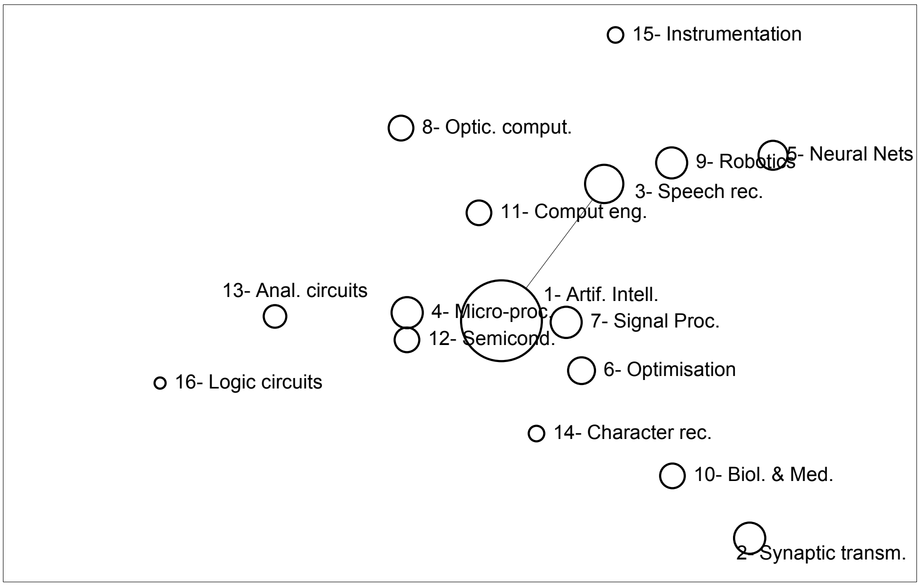
As an experiment we also explored the reverse procedure, in order to reconstruct the "real" present from the past. Here, the structure of the 'oldest' year (the past, e.g., ***t-4***) is taken as starting point. Subsequently, interactions between and within subfields are examined for subsequent years (***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).

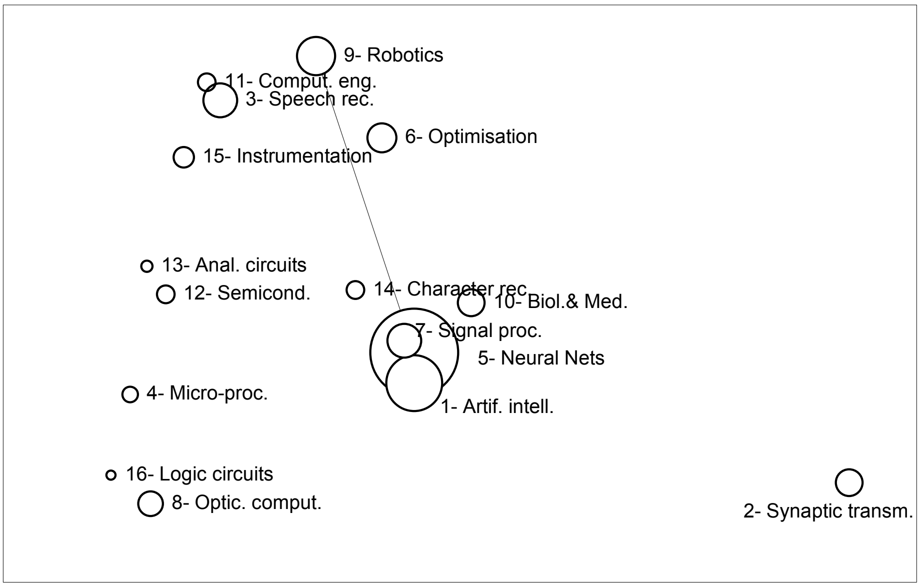
6.5 Results and discussion

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.



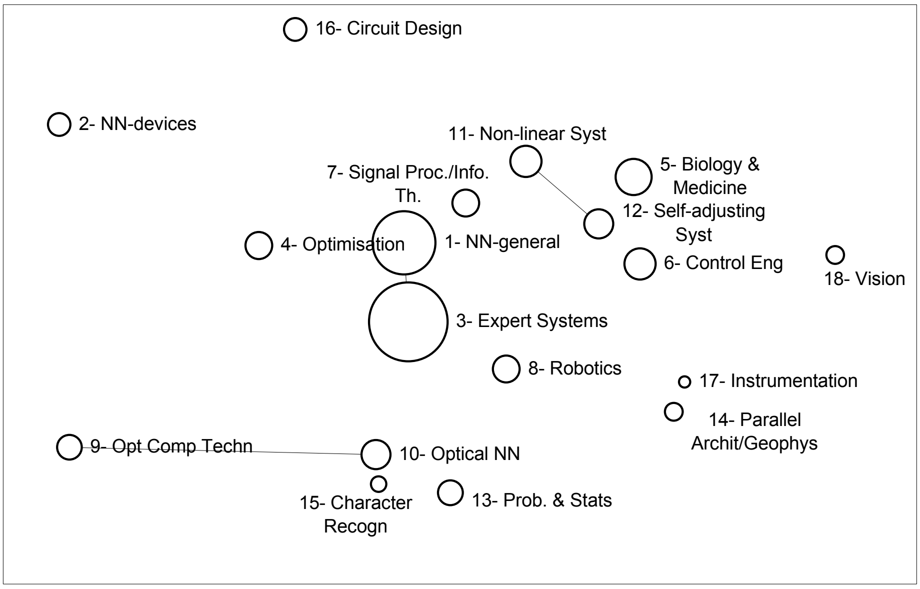
(a) 1989/1990 based on 1989/1990 data



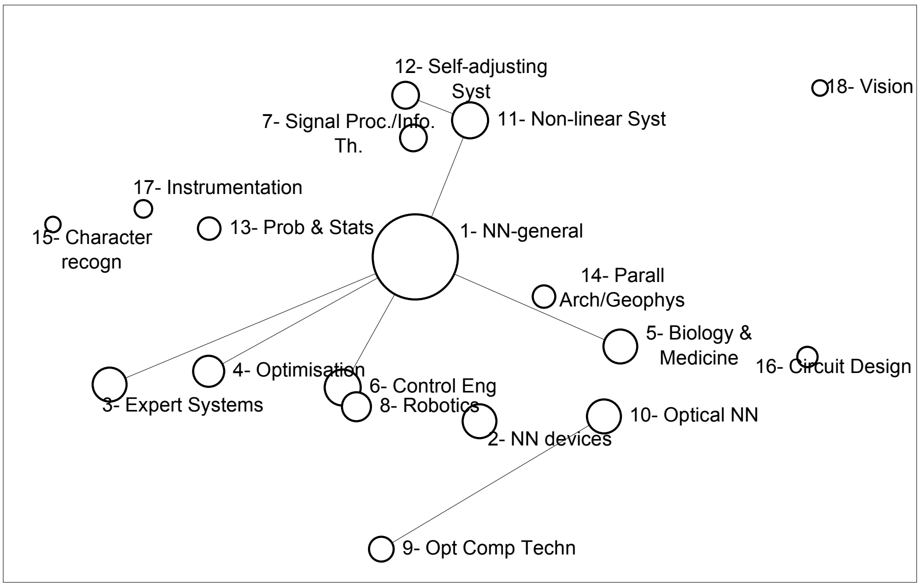
(b) 1992/1993 based on 1989/1990 data

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

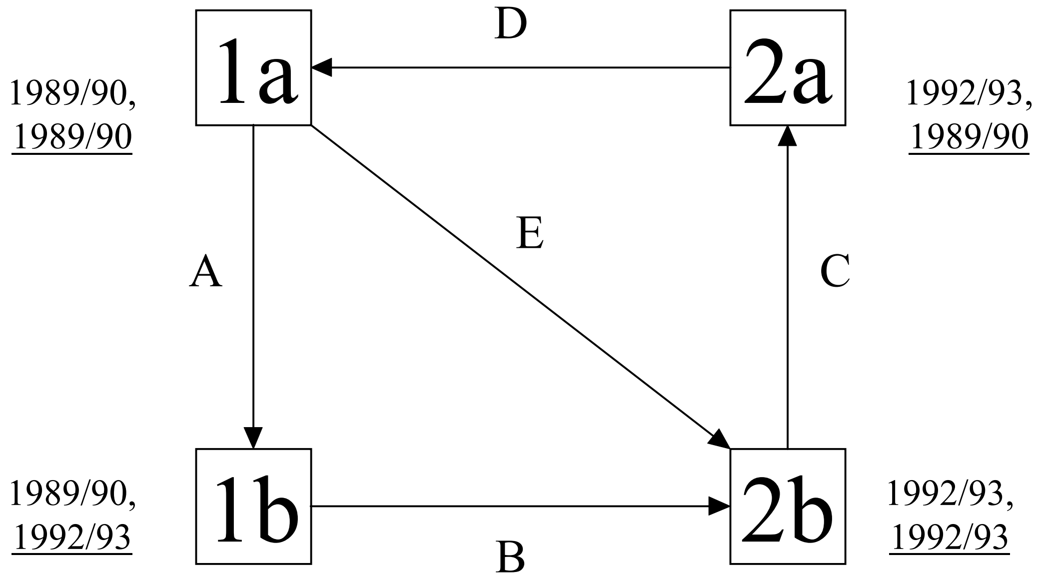
2-dimensional representation of sub-fields. Definition of sub-fields based on clusters of the most important classification codes in 1992/1993. Cluster size (surface area) represents the proportion of publications included in each sub-field. Lines between sub-fields indicate relatively high number of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

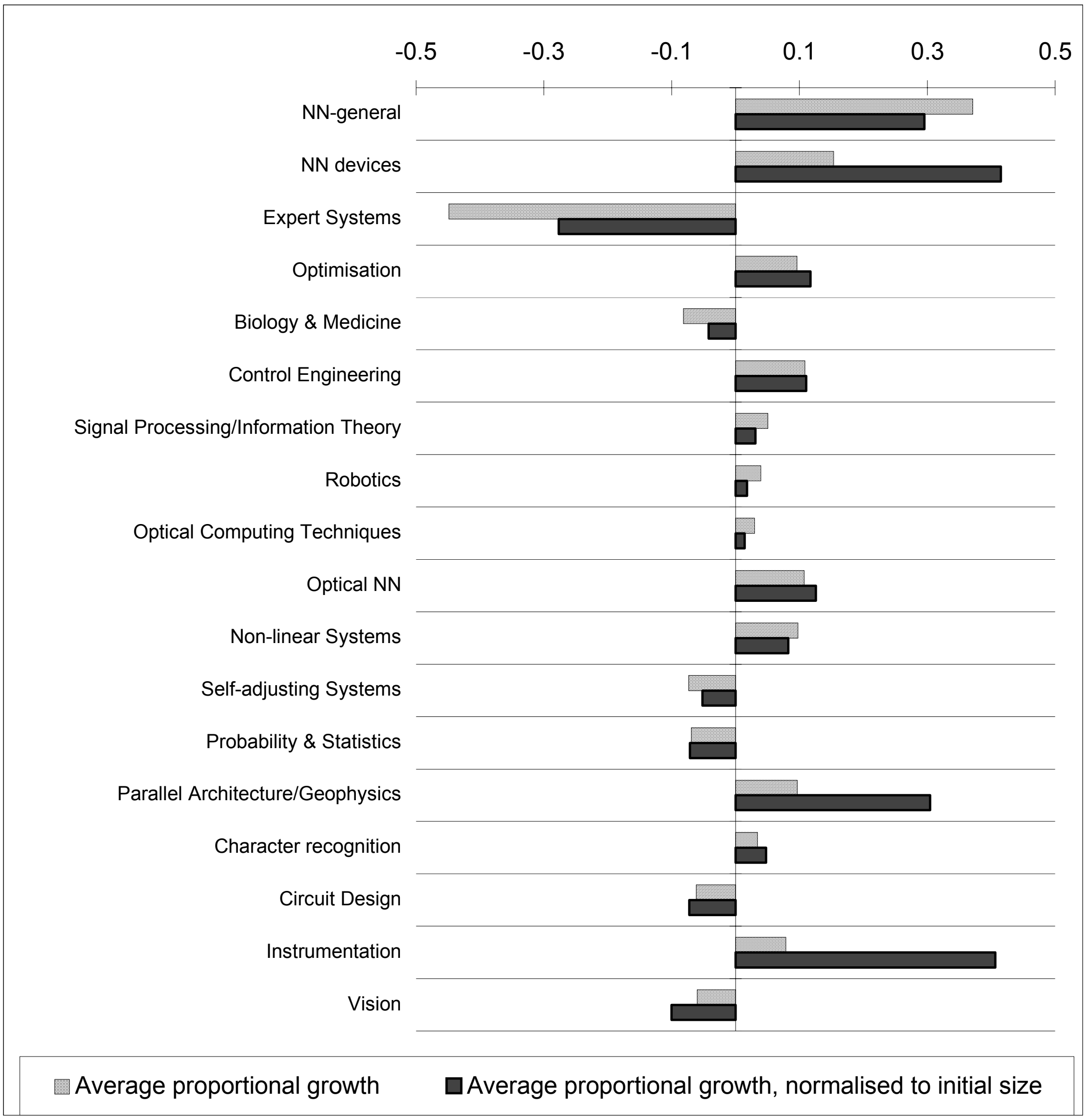
We think these transformations and comparisons have interesting potentials as devices to identify successful pathways or dead end trajectories, and, in addition, to identify leading actors in the field, pointing to future developments. We therefore intend to apply this approach in current work for further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

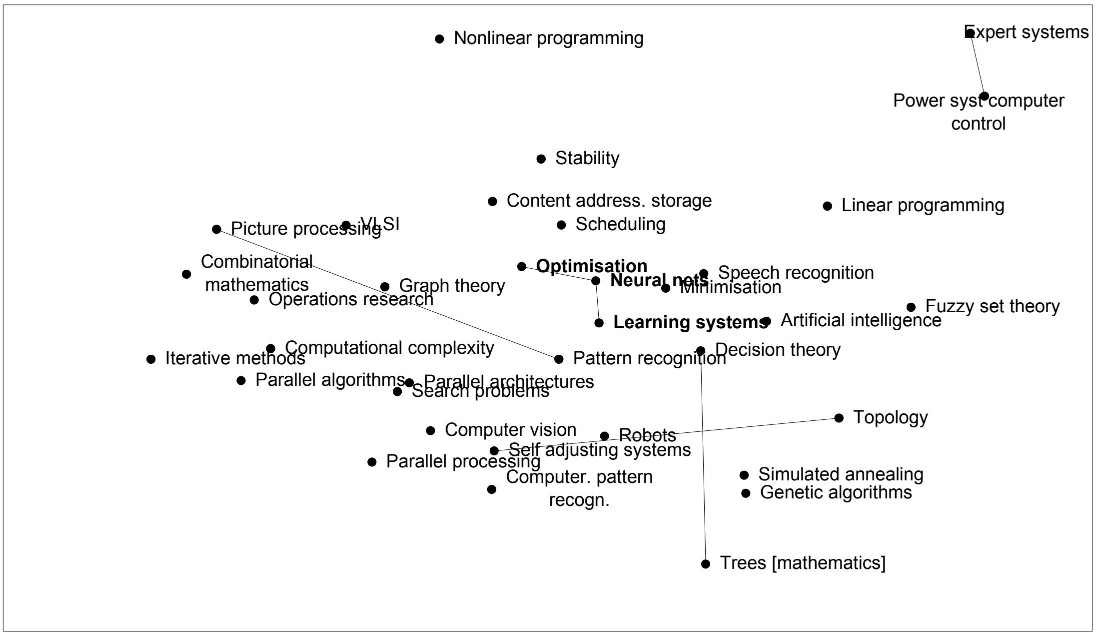
Figure 6-4 Evolution of sub-fields in Neural Network Research from 1989/1990 (based on 1992/1993 data) to 1992/1993

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.

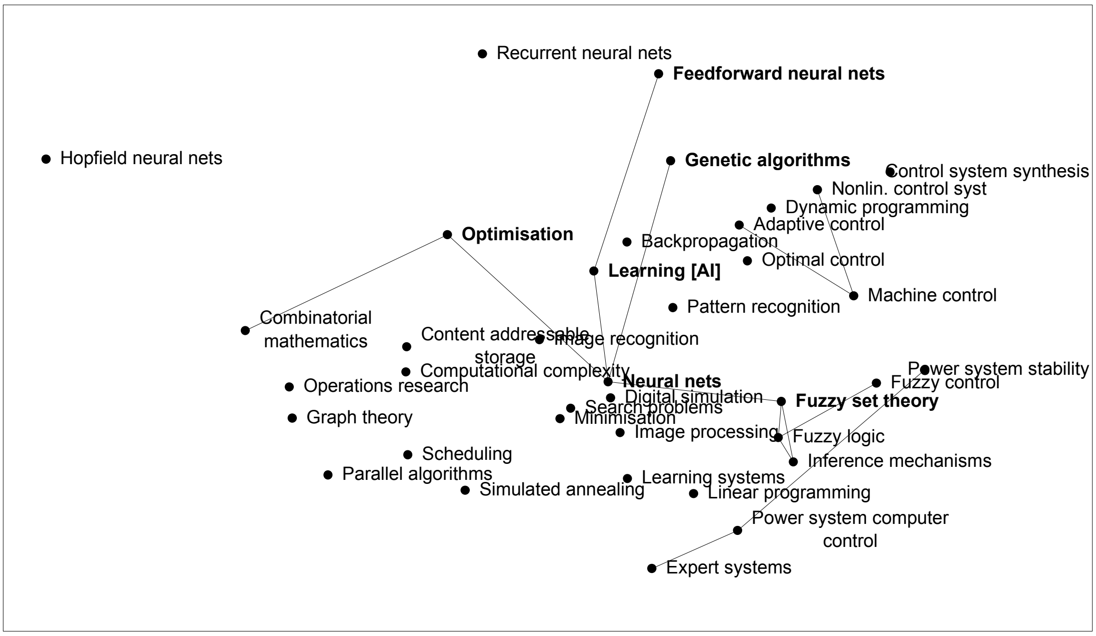
6.5.2 Observations with the detailed subfield-maps: the fine structure of the field

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).

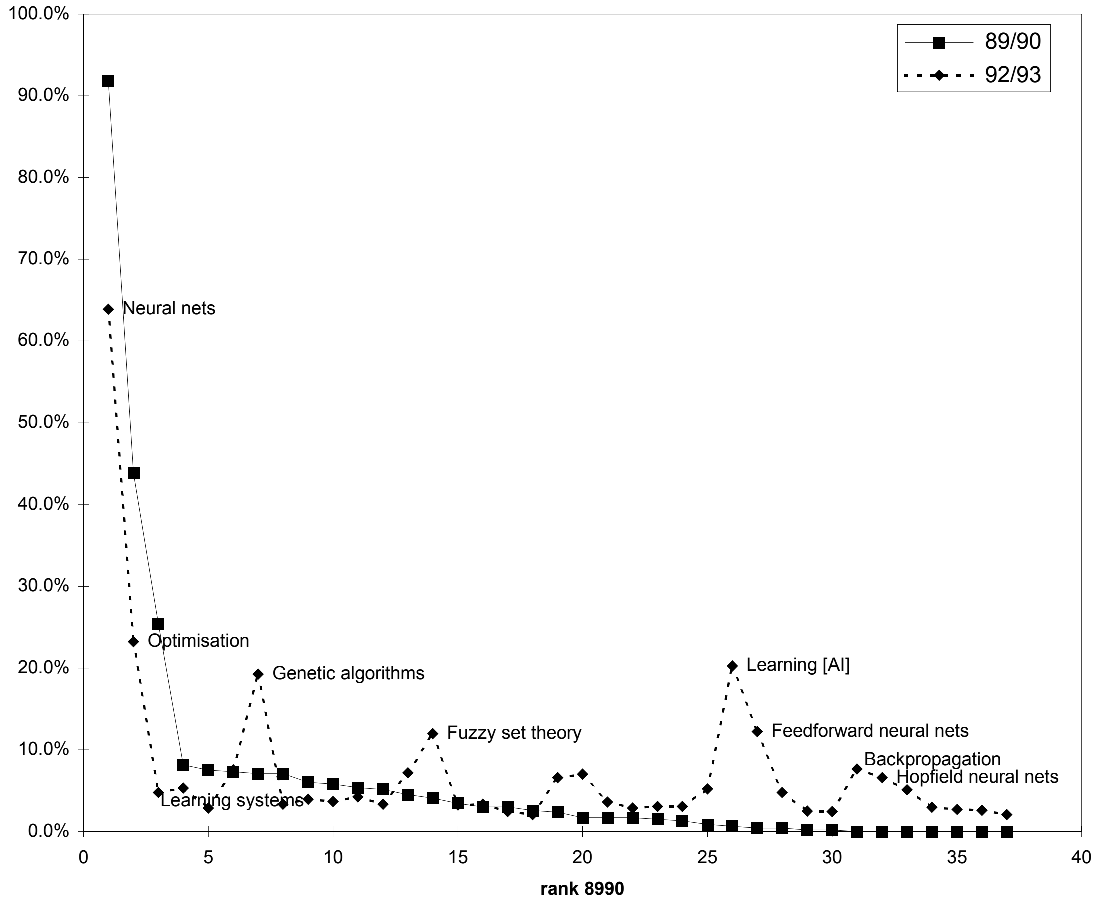
Figure 6-5 Maps of sub-field 'Optimization' (a:1989/1990, b:1992/1993)

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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