Timeline and Crossmap Visualization of Patents

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Abstract

We have explored the extension of timeline and crossmapping techniques to visualizing of collections of patents that cover a technological specialty. We first present a network model of collections of patent records and discuss this model and its application to mapping patents. The usefulness of these mapping and visualization techniques is demonstrated using a collection of patent abstracts gathered from the USPTO that cover the subject of DVD optical pickup technology.

1 Introduction

1.1 The objectives of patent analysis.

Patents are the main record of technological innovation, and are used widely as indicators for scientific and technological activities. Far beyond this, patents are also a main source of competitive technical intelligence (CTI). Detailed mining of patent literature is proven to be useful for competitive intelligence, which can expose many aspects of technology activity, such as technology trends, competitor changes, and activity of companies. Patent analysis can be helpful for decision making in enterprises (Coburn, 1999; Porter, 2005).

Understanding the trends of a technological specialty, finding the technological subtopics, finding the key technology innovations of the technological subtopics, and identifying the main technical competitors yields information that is especially useful for CTI in enterprises. Patent analysis, evaluating and understanding trends in the development of technologies, and in the competitive positioning of organizations within areas of technology, as well as finding the key innovations which can be borrowed, is a useful tool for a company's technology competencies.

1.2 The use of patent visualization.

Visualization methods are considered to be proper for representing patent information and its analysis results. Therefore, patent visualization is a key tool for patent analysis and detection of technical opportunities.

There are more and more tools that allow one to download and analyse patents in one way or another. Most of them can provide the user with automatic analysis enabling them to map most of the interactions (applicants, IPC, inventors, and dates) from the patent data source and to map the citation links among the patents. In this paper, we propose a useful visualization method and tool based on patent bibliometrics for understanding the structure and dynamics of development in a technological specialty, which can yield detailed and actionable information about a technological specialty. We explore the extension of timeline and crossmapping techniques (Morris, et al 2003; Morris & Yen, 2004) to visualizing of collections of patents that cover a technological specialty, and try to answer the following questions:

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1) What are the technological subtopics?, 2) What is the important prior art used by innovations in the specialty?, 3) Which institutions and inventors are active in the specialty, and which among them produce important innovations?, 4) Which institutions are 'borrowers' of innovations, and from which 'source institutions' do they draw?

1.3 Review of previous patent literature.

A large literature exists concerning the use of patents to compare innovation in various countries, to measure knowledge flows between technologies or regions, to analyse the localization of technology and technology trends, to ascertain quality of inventions, or to evaluate the R&D policy of firms within or outside a country. Among these literatures, what has been of central interest is patent citation analysis, which can be divided into two types, patents citing journal articles, and patents citing patents. Our research focuses on the relationships established by the citing and cited patents only, especially patent bibliographic coupling and patent co-citation. We believe these metrics convey more valuable information about covered technologies than patent citing articles.

Mogee and Kolar (1999) used patent co-citation clustering to identify the major technology fronts pursued by a business firm. Almost 3,000 pharmaceutical patents were organized into 13 groups without the need for an expert to read and classify each. Lai and Wu (2005) used the patent co-citation approach to establish a patent classification system. Huang, et al. (2003) showed that bibliographic coupling is useful to find the relationships among companies and used multidimensional scaling to map the results. They used bibliographic coupling analysis to plot out a patent citation map of 50 high-tech electronic companies in Taiwan to distinguish the difference between companies, industry sectors, and their technologies. Lo (2008) used the patent coupling approach to reveal the possible linkage among 40 primary organizations in genetic engineering research. Kuusi and Meyer (2007) suggested that bibliographic coupling is particularly suitable for anticipating technological breakthroughs. They employed bibliographic coupling to identify important nanotube related 'leitbilder', a concept meaning 'guiding images' that provide a basis for different professions and disciplines to work in the same direction.

Until recently, co-citation and bibliographic coupling have been applied rarely for purposes of competitive technical intelligence in enterprises.

1.4 Summary of the paper.

Presentation of theory. Given a technology-specific collection of patent records, we employ a network model of the collection for analysis. The collection of patent records is considered a network of bibliographic entities of different entity-types. The primary entities are the patents themselves. Dependent entities are linked to the patents in which they occur. Links between dependent entities are calculated through the links to patents. For mapping and analysis purposes, bibliographic entities, links and entity groups in the collection of patent records represent physical entities, links and groups.

The CTI in the technology specialty for enterprises are manifested in the collection of patents as groups of related entities, such as groups of patents that represent technologies, groups of cited patents that represent base technologies, and groups of patent inventors that represent development teams. Exploration and visualization of these groups and the complex relations among them provides information that can be used to gain a broad and detailed understanding of the underlying CTI about technologies, main competitors and developers. A company can apply the timeline and crossmapping techniques to identify core technological fronts of its patent portfolio, or technological fronts where it might face stiff competition. Also to find the key innovation main competitor and developers in each technological front and grasp opportunities that may exist.

Case study results. Our case study, DVD optical pickup technology, is an active specialty that is seen as a key technology for the Chinese consumer optical disk player industry. After acquiring and installing a U.S. patent abstract database covering 1976 to 2004, we used a series of queries to build a collection of patents covering DVD optical pickup technology. This

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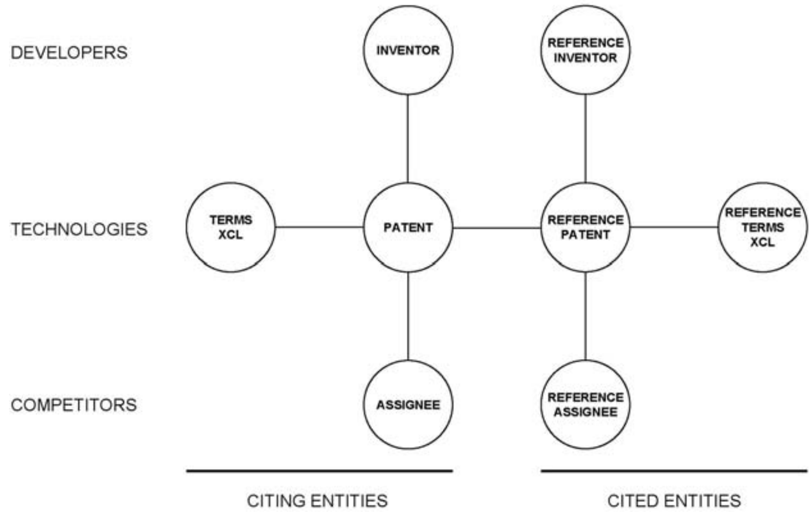

Figure 1. Network model of a collection of patent records.

collection consists of 515 patents, associated with 93 assignees, and citing 3397 reference patents. We present and discuss four visualizations of this collection: 1) a technology front timeline, 2) a technology front to reference patent crossmap, 3) a technology front to assignee crossmap, and 4) a technology front to inventor crossmap.

Using the technology front timeline map we can identify the technological development fronts in the specialty, find emerging technology threats and opportunities, and visualize overall technological trends in the specialty. The technology front to assignee crossmap is useful to identify specific main competitors in each technological front, and the strength or weakness for each competitor. Via the technology fronts to reference patents crossmap it is easy to find the key innovations in this technology area of interest. The technology front to inventor crossmap shows cross company collaboration as overlap of inventors over assignees. The details of the specific useful information extracted from these maps will be discussed.

2 Method

2.1 Summary of proposed patent analysis method.

The basic method of analysis that we propose is based upon clustering a topic-specific collection of patents into technology fronts, and mapping those technology fronts against time and against other entities in the patent collection. This analysis and visualization yields information on the structure and dynamics of the technology of interest.

The steps of the proposed mapping technique are as follows:

1. Gather a collection of patents.
2. Extract a network of bibliographic entities.
3. Cluster patents into technology fronts using bibliographic coupling.
4. Label and analyse technology fronts.
5. Visualize technology fronts as a timeline.
6. Cluster other entities using cooccurrence.
7. Visualize technology fronts against other entity groups using the crossmap technique.

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2.2 Basic theory.

Given a technology-specific collection of patent records, we employ a network model of the collection for analysis. This model is similar to the model of a collection of journal papers proposed by Morris (2005). The collection of patent records is considered a network of bibliographic entities of different entity-types. The primary entities are the patents themselves. Secondary entities are linked to the patents in which they occur. Links between secondary entities are calculated through the links to patents.

Figure 1 shows a diagram of the network model of patents. The model consists of 8 bibliographic entities of most interest to patent analysts:

1. Patents.
2. Inventors.
3. Assignees.
4. Index terms (XCL classification).
5. Reference patents.
6. Reference inventor.
7. Reference assignee.
8. Reference terms (XCL classification).

We define *bibliographic entities* as those entities that occur in the collection of patent records. *Bibliographic links* are the connections between entities as defined in the network model. Bibliographic links can be divided into two types of links: 1) *occurrence links*, and 2) *cooccurrence links*. Using cooccurrence links, bibliographic entities can be clustered into *bibliographic coocurrence groups*, which class entities by their tendency to have a set of attributes in common.

Physical entities are the real-world entities of interest that are being mapped. We can also define *physical links* (both occurrence and cooccurrence) and *physical entity groups* as items analogous to bibliographic links and groups in bibliographic networks.

For mapping and analysis purposes, bibligraphic entities, links and entity groups in the collection of patent records represent physical entities, links and groups. This is analogous to the connection between bibliographic networks and research specialty networks when mapping research specialties from collection of journal papers (Morris and Martens, 2008).

For our purposes we make the following basic assumptions concerning entities, links, and entity groups. Bibliographic patents represent technologies, defined as distinct technological techniques that can be identified by specific claims. Reference patents represent base technologies, defined as prior art technologies upon which new technologies are built. It is assumed that base technologies can be ranked in importance based on the number of times they are used by new technologies. Unimportant technologies are seldom used, while important technologies are used repeatedly.

We assume that a bibliographic inventor corresponds to the developer of a technology. The bibliographic assignee corresponds to the owner of a technology, that is, the legal entity that licenses the technology covered by the patent. The index terms, as intended by their creators and users, correspond to classes of technology. These correspondences are summarized in Table 1.

Table 1: Catalogue of bibliographic entities and the physical entities that they represent.

Bibliographic entity	*Corresponding physical entity*
Patent	Technology
Inventor	Technology developer
Assignee	Technology owner
Index term	Technology class
Reference patent	Base technology
Reference inventor	Base technology developer
Reference assignee	Base technology owner
Reference index term	Base technology class

Considering bibliographic occurrence links, the most important consideration is the assumption that the citation of a patent corresponds to the *use* of one technology by another. We assert that this assumption is generally true, but allow that there may be exceptions, such as when a patent is cited to draw attention for contrast or comparison purposes. Other important occurrence links are from inventor to patent, and from assignee to patent. We can make the straightforward assumption that the former bibliographic link corresponds to creation of a technology by a developer, while the latter link corresponds to ownership of a technology by an owner. Table 2 summarizes some important bibliographic links and their corresponding physical links.

Table 2: Catalogue of important bibliographic occurrence links and the physical links that they represent.

Primary entity	*Secondary entity*	*Physical link*
Patent	Inventor	Technology was created by a developer
Patent	Assignee	Owner possesses the technology
Patent	Reference patent	Technology uses a base technology
Reference patent	Reference inventor	Base technology created by a base technology developer
Reference patent	Reference assignee	Base technology possessed by a base technology owner

When considering cooccurrence links, it is important to consider the concept of co-use of technologies. Two reference patents cited by the same patent denote co-use of two base technologies by some new technology. Two patents that cite the same reference patent, however, denote the use of the same base technology by those two newer technologies. We can also consider two inventers listed on a patent as co-developers of the technology denoted by the patent.

Because only one assignee is associated with each patent, we cannot infer links between assignees by cooccurrence in patents. It is possible to calculate links between assignees through reference patents. From cooccurrence of these links we can infer links between technology owners whose technologies use the same base technologies. Table 3 summarizes the representation of several important types of cooccurrence links.

Table 3: Catalogue of important bibliographic cooccurrence links and the physical links that they represent.

Primary entity pair	*Secondary entity*	*Physical link*
Patent	Reference patent	Two technologies use same base technology
Reference patent	Patent	Two base technologies used by same technology
Inventor	Patent	Two developers co-developed a technology
Assignee	Reference patent	Two technology owners use the same base technology
Index terms	Patents	Two technology classes correspond to same technology

Based on the preceding discussion, it is possible to examine groups of bibliographic entities that have been clustered by cooccurrence and infer their representation of groups of physical entities. The most important of these groups, and the basis for the analysis proposed in this paper, are groups of patents clustered on cooccurrence of references cited. These groups are analogous to groups of journal papers clustered using bibliographic coupling (Kessler, 1963). We can infer that these are technologies that are using the same base technologies. We will refer to these groups as technology fronts in this paper, in analogy to research fronts of journal papers (Persson, 1994). Groups of cocited patents can be considered as groups of co-used base technologies. Table 4 summarizes several important cooccurrence derived bibliographic groups and the physical groups that they can be considered to represent.

The theory discussed above lays the basis for mapping the important elements of technological developments through a collection of patent records. The basic step of the proposed method, clustering patents into technology fronts, allows mapping the dynamics of technological development. The technology fronts, being groups of patents (technologies) that tend to use the same base technologies, correspond to ‘lines of devel-

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opment,' that is, technological solutions to problems that use the same technology.

Table 4: Catalogue of important bibliographic cooccurrence links and the physical groups that they represent.

Primary entity group	*Secondary entity*	*Physical group*
Patent	Reference patent	A group of technologies that use the same base technology. Technology fronts.
Reference patent	Patent	A group of base technologies that are co-used by technologies
Inventor	Patent	A group of developers that co-create technologies, i.e., a development team
Assignee	Reference patent	A group of technology owners whose technologies are based on the same base technology
Index terms	Patents	A group of technology classes that denote similar technologies

Other than technology fronts, to explore the other aspects of a technology of interest, it is useful to map: 1) the base technologies used, 2) the developers of new technology, and 3) the owners of new technology. The theory discussed above lays the foundation for the mapping procedure proposed in this paper.

2.3 Patent mapping procedure.

The mapping procedure used here is based on gathering a topic-specific collection of patent records. A step by step description of the method follows.

Gathering of a collection of patent records. A collection of patent records can be gathered from a commercial database service or from a database purchased from patent issuing government agencies. The collection can be gathered using several methods: 1) queries against index terms and abstract text, 2) gathering patents that cite a set of seed patents, or 3) gathering patents according to primary or secondary patent classification.

Extraction of entities. For the basic technology front analysis, it is necessary to have a table of citing to cited patents. Further analysis of inventors and assignees requires tables listing patents and their associated inventors and assignees. For analysis of index terms, a table of patents and their associated primary and secondary classifications is required. The reference inventor, reference assignee, and reference index terms tables are built using queries back to the full database. The tables are converted to a series of matrices to form the network model as described in Morris (2005).

Extraction of cooccurrence links. Cooccurrence links between entities are usually calculated using matrix multiplication. In the case of non-binary occurrence matrices, it is necessary to use a generalized matrix multiplication method to calculate cooccurrence counts (Morris, 2005). When this is necessary, we use generalized matrix multiplication to implement the overlap function (Salton, 1989) for calculating cooccurrence counts.

Clustering. Clustering is performed on cooccurrence counts normalized to similarities using the dice function (Salton, 1989). Interpair distances are calculated by subtracting similarities from unity. Clustering is performed using hierarchical agglomerative clustering with Ward's method linkage (Gordon, 1999). This method allows construction of a dendrogram that is very useful for visualization purposes.

Technology front analysis. Patents are clustered into groups by coocurrence of cited patents. From this analysis a 'technology front report' is generated, which lists the patents, with their titles, in each technology front, and gives ranked lists of entities associated with those patents. Such entities include 1) cited patents, 2) inventors, 3) assignees, and 4) primary and secondary patent class. This report is given to a subject matter expert or analyst to extract technology front labels based on themes found in titles of the patents in each research front.

Patent cocitation analysis. In this analysis, the reference patents are clustered by cocitation. This yields groups of reference patents representing co-used base technologies. The resulting groups are visualized using crossmaps to show

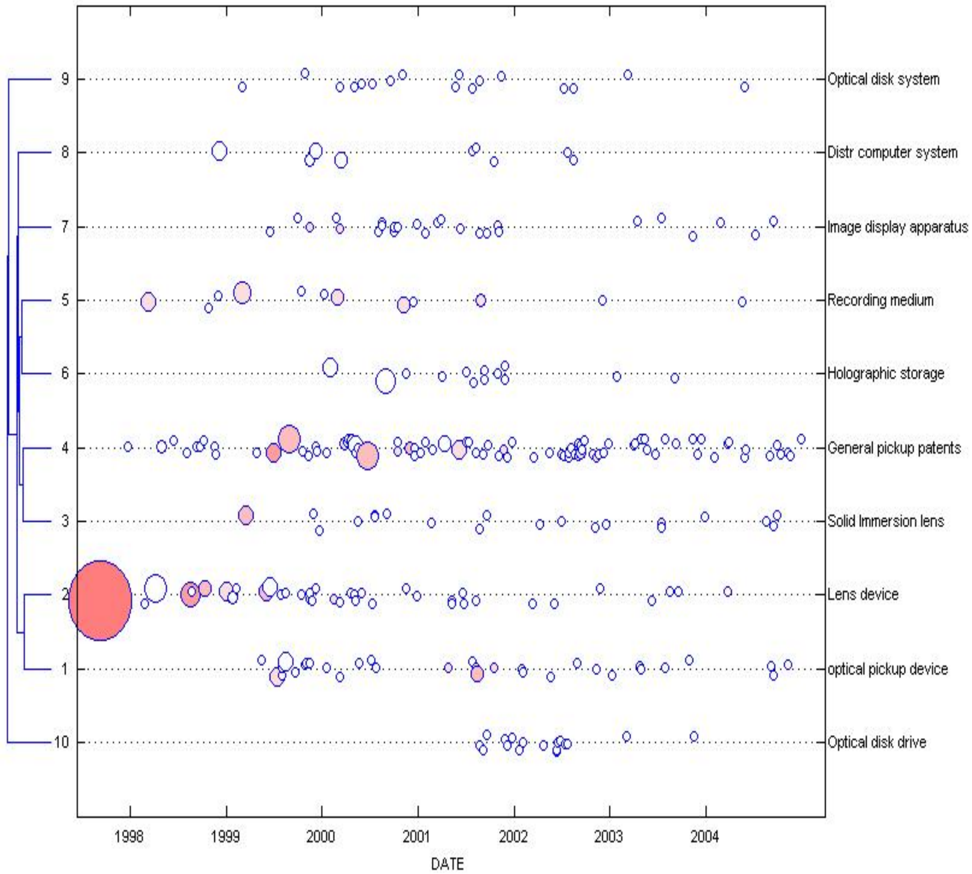

Figure 2. Timeline of patent technology fronts.

correspondence of base technologies to technology fronts.

Co-inventor analysis. In this analysis inventors are clustered by co-occurrence in patents. This analysis yields groups of inventors that correspond to development teams. The groups are crossmapped against technology fronts to show correspondence of development teams to technology fronts.

Assignee analysis. To analyse assignees, we cluster assignees by cooccurrence of their associated patents in technology fronts. This yields groups of assignees that tend to own technologies in the same technology front. Crossmap visualization is used to show the correspondence of assignee groups to technology fronts.

The mapping procedure described above yields information on the technology fronts in the area of interest, the correspondence of technology developers, technology owners and base technologies to those technology fronts. The results of the analysis described above are visualized to better understand the dynamics of the area of interest, and also to show correspondence of developers, technology owners, and base technologies to technology fronts.

2.4 Visualization techniques.

Timelines. Timelines are used to display technology fronts, and are a technique borrowed from visualization of collections of journal papers (Morris *et al*, 2003). Figure 2 shows an example of a timeline. The patents are plotted as circles by issue date on the x-axis. Patents are plotted on the y-axis in horizontal tracks by technology front. The vertical placement of the tracks corresponds to the clustering dendrogram,

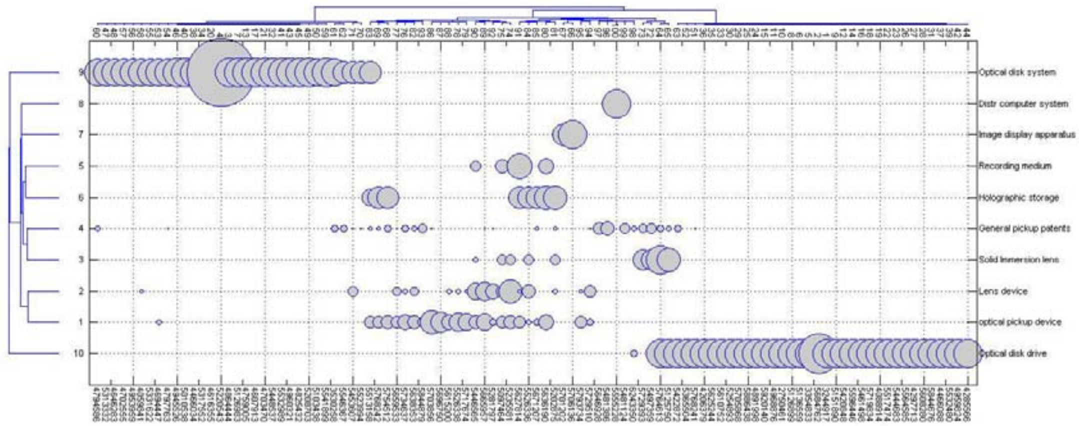

Figure 3. Crossmap of technology fronts to reference patents. .

which is placed on the left of the plot. The technology front labels are shown on the right side of the plot. The circle size corresponding to individual patents is proportional to the number of times the patent has been cited in the dataset. This highlights patents that correspond to important base technologies. The shading of each circle is proportional to the number of times the corresponding patent has been cited in the last year. This highlights patents that correspond to base technologies that are currently being heavily used.

Through the dendrogram, the timeline shows the structure of technology fronts. The temporal plotting of patents reveals which technology fronts are currently active and which are obsolete. Overall, the timeline visualization gives a good visualization of the structure and dynamics of the technology fronts in the technology area of interest.

Crossmaps. Crossmaps are matrix-based visualizations of the links between groups of entities in the collection of patents (Morris & Yen, 2002). In our analysis, we use crossmaps of technology fronts to some other entity groups in the dataset. Figure 3 shows an example of a crossmap, in this case between technology fronts and reference patents. The y-axis corresponds to technology fronts and has the same horizontal positions, dendrogram and labels as the technology front timeline. The x-axis corresponds to the other entity, with the entity positions determined by the clustering dendrogram, which is displayed at the top of the map. The labels for the x-axis entities are displayed along the bottom of the map.

The circles in the plot correspond to some correspondence metric between the x-axis entity and the y axis entities. In Figure 2 the circles sizes are proportional to the number of patents in the technology front that cite a reference patent at a particular x-axis position. Given research front *i* on the y-axis, and reference patent *j* on the x axis, the circle at position (*i*, *j*) on the map is proportional to the number of patents in technology front *i* that cite reference patent *j*. The crossmap is very useful for showing correspondence of entities of different types to technology fronts, very useful information. The technique also displays overlap in correspondence, and visualized core entities well.

3 Data

To demonstrate the mapping methods outlined in Section 2, a dataset was constructed covering patents on the topic of optical disk drive pickups. The source data for this study was extracted from a database containing bibliographic data of United States patents from 1976 to 2004. In this database each record corresponds to a US patent, and the items in the records correspond to the summary data provided on the first page of the patent. This includes the patent number, cited patents, title, inventor names, assignee, date of issue, abstract text, primary patent class, and secondary patent classes.

The collection of patent records was extracted using the following query against patent

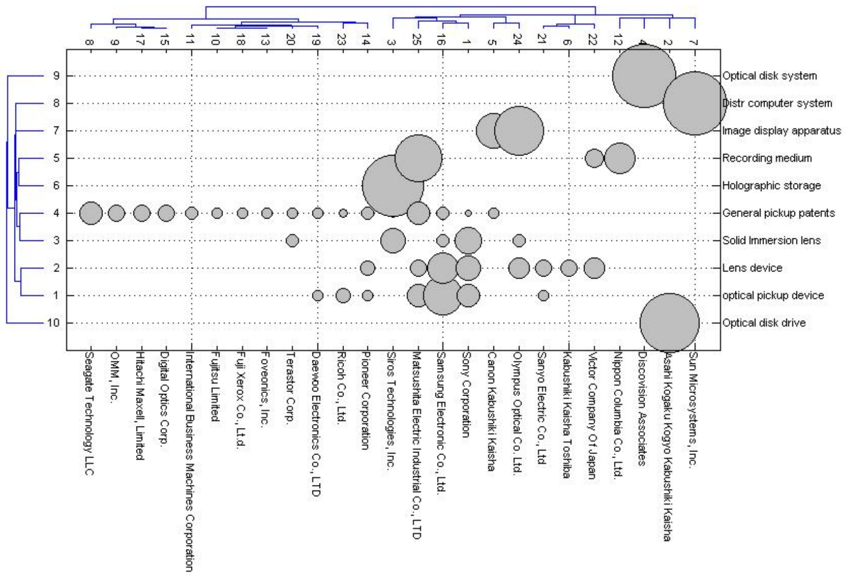

Figure 4. Crossmap of technology fronts to assignees .

titles: *('optical head' OR pickup OR pick?up) AND (year > 1995 and year < 2004).* After download of records resulting from this query, further queries against the database were used to find reference patents. Reference assignees, inventors, and index terms could be easily found, but were not used because of the limited scope of this demonstration study.

After acquisition, the dataset consisted of 515 patents, with 15017 citations to 3397 reference patents. There were 695 inventors, and the patents were issued over the period of 1997 to 2004.

4 Results

4.1 Clustering statistics

Technology fronts. For clustering into technology fronts, patents that did not have 4 or more reference patents in common with some other patent were excluded, resulting in 272 patents being retained for technology front analysis. Clustering was performed as described in Section 2, and the clustering tree was truncated to produce 10 technology fronts.

Reference patents. Reference patents that were cited fewer than 17 times were excluded from clustering, resulting in 106 reference patents being retained for analysis. Clustering was performed down to 106 singleton clusters.

Inventors. Inventors associated with fewer than 5 patents were excluded from clustering, resulting in 59 inventors retained for analysis. Clustering was performed down to 59 singleton clusters.

Assignees. Assignees were clustered based on common membership in technology fronts. Assignees with fewer than 3 patents on the technology front map were excluded from clustering, resulting in 25 assignees being retained for analysis. Assignees were clustered down to 25 singleton clusters.

4.2 Technology front analysis and patent timeline

Figure 2 shows the timeline for the optical disk drive patent dataset. Using the abbreviation TF for 'technology front,' and proceeding from top to bottom, TF 9 to TF 7 cover patents on optical disk systems, while TF 5 and TF 6 cover storage media, TF 4 is a general cluster on optical pickup patents. TF 3 and TF 2 cover pickup lens, while TF 1 covers specific pickup devices. TF 10 at the bottom of the timeline is specific to one assignee, covering a specific type of optical disk drive. The earliest developments in this patent set appears to be TF 2 on lens devices.

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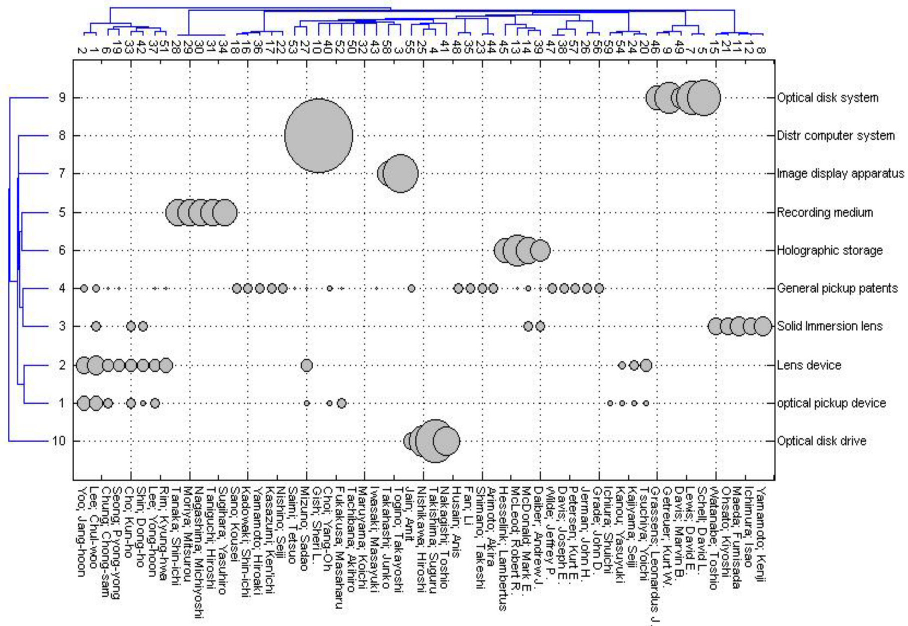

Figure 5. Crossmap of technology fronts to inventors .

This technology front contains a heavily cited patent that denotes a well used base technology on lens design. It can be seen that the systems and storage medium technology fronts (TF 9 down to TF 6) have been declining since 2002, while most recent development is concentrated in TFs 4 down to 1, possibly reflecting progress in lens technology.

4.3 Technology front to reference patent crossmap

Figure 3 shows a crossmap of technology fronts to reference patents. In the map, the circle size is proportional to the number of patents in the specified technology front that cite the specified reference patent. Note, as previously stated, that the technology fronts on the y axis are identical to those in the timeline of Figure 2. The crossmap shows a lack of core reference patents, which generally shows as long vertical patterns of circles on this type of map. It is easy to see the TF 9 at the top and TF 10 at the bottom of the map are based on distinct sets of reference patents, although there is some overlap of reference patents: Reference Patent 83 between TF 9 and TF 6, and Reference Patents 64 and 65 between TF 10 and TF 3. While TF 8 and 7 are based on reference patents that are unique to those technology fronts, the remaining technology fronts from TF 5 to TF 1 tend to rely on an overlapping set of reference patents. Further investigation of the reference patents that are distinct to specific technology fronts, and those that overlap, would allow delineation of the specific base technologies and general base technologies respectively.

4.4 Technology front to assignee crossmap

Figure 4 shows the assignee to technology front crossmap. On the map, the circle size is proportional to the number of patents in the specified technology front that are associated with the specified assignee. This map shows, on the right, that technology in TF 9, 8, and 10 are uniquely owned by Discovision, Sun Microsystems, and Asashi Kogaku respectively. Other assignees tend to overlap in their ownership of technologies, particularly Matsushita Electric, Samsung Electronic Co., and Sony Corporation. Note the large number of assignees owning technology in TF 2, an indication of the importance of lens devices in optical drives.

4.5 Technology front to inventor crossmap

Figure 5 shows a crossmap of inventors to technology fronts. On the map, the circle size is proportional to the number of patents in the specified technology front that are associated with the specified inventor. From the lack of vertical overlap in this plot, it is easy to see the inventors fall into distinct non-overlapping development teams. It is possible to build a crossmap of inventors to assignees that would plainly show the affiliation of the team members on the map. From such a map it would be possible to infer movement of developers from one company to another and also to show transfer of teams resulting when one company is acquired by another. On the left of this map, from Inventor 2 on the left to Inventor 51 on the right is a group of Korean developers that are working on multiple overlapping technologies. While all of this group works on TF 2, 'optical pickup devices', only selected members of the group work in TF 2 (lens devices) and TF 1 (optical pickup devices). The map can thus possibly be used to infer the technical talents of individual development team members within the group. By the team members' participation in these technology fronts, using the assignee crossmap we can infer that the developers are affiliated with Samsung Electric Co.

5 Discussion

The mapping and visualization techniques presented here are comparable to similar techniques that have been applied to collections of journal papers (Morris and Boyack, 2005). It is important, however, to note the differences in the correspondence of entities in patent collection from those in journal paper collections. For example, journal papers can be considered as research reports that correspond to research tasks, but patents correspond to technologies. References in journal papers can be considered to represent base knowledge applied to research tasks, while reference patents represent base technologies (prior art). Section 2 of this paper is a detailed attempt to establish a foundational theory for mapping patents.

The techniques presented here can be readily extended to worldwide patents if the patents records can be gathered in a unified format. Such analysis could allow visualization of technology diffusion across international boundaries.

The visualization techniques can also be easily extended to patent classes. In fact, a crossmap of technology fronts to patent classes would facilitate labelling of those technology fronts and also help to identify cross-disciplinary technological development and technology borrowing across technological fields.

It is further possible to extend the crossmapping technique to produce a crossmap of assignees (citing assignees) to reference assignees. This would allow a visualization of 'technology borrowing' from one assignee to another, and allow 'technology creator' enterprises to understand by whom their technologies are being exploited.

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