INTER-FIRM R&D NETWORKS IN THE GLOBAL SOFTWARE INDUSTRY: AN OVERVIEW OF MAJOR TRENDS AND PATTERNS

Myriam Cloodt*

John Hagedoorn **

Nadine Roijakkers ***

May 4th, 2007

* Department of Organization Science and Marketing
Faculty of Technology Management, Eindhoven University of Technology
P.O. Box 513, 5600 MB Eindhoven, The Netherlands
Tel: (31) 40-2474187, Fax: (31) 40-2468054
m.m.a.h.cloodt@tm.tue.nl

** Department of Organization and Strategy and UNU-MERIT
Faculty of Economics and Business Administration, Maastricht University
P.O. Box 616, 6200 MD Maastricht, The Netherlands
Tel: (31) 43-3883823, Fax: (31) 43-3884893
j.hagedoorn@os.unimaas.nl

*** Atos Consulting
Papendorpseweg 93, Building C, 3528 BJ Utrecht, The Netherlands,
Tel: (31) 6-20496457, Fax: (31)10-2644085
nadine.roijakkers@atosorigin.com

Acknowledgements: We thank Marc van Ekert, Boy Kessel, Josien Suntjens, and Rob Webbink for their research assistance.

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Abstract

This paper presents an analysis of some major historical trends and changing patterns in inter-firm R&D partnering in the international software industry during the period 1970-1999. Our research demonstrates an overall growth pattern of newly made R&D partnerships and reveals the important role played by leading firms. We also examine the emergence of various R&D partnering networks in the software industry, which cannot be seen separately from some important developments in the computer industry. This part of the analysis indicates the change from rather sparse and disconnected inter-firm R&D networks into dense and well-connected networks, based on shifts in product markets and the need for new business models during the second half of the 1980s.

(115 words)

INTRODUCTION

The main purpose of this paper is to analyze major trends and patterns in inter-firm R&D partnering and R&D networks in the international software industry established during the period 1970-1999. R&D partnerships are defined as inter-firm cooperative agreements, where companies share assets and resources for joint R&D through a variety of inter-organizational modes such as R&D pacts, joint development agreements, and R&D joint ventures. As shown by Hagedoorn (2002), Mowery (1996), Mytelka and Delapierre (1987) and the National Science Board (2000), these inter-firm R&D partnerships play a crucial role in the formation of inter-firm networks in the information technology (IT) industry and high-tech industries in general. As demonstrated below, an analysis of major trends and patterns in R&D partnering in the software industry cannot be seen independently of some of the major trends in the computer hardware industry (see also Cloodt, Hagedoorn, Roijakkers, 2006). Hence, our business historical analysis is not possible without highlighting several of the major developments in the computer hardware industry, since with each new computer technology a parallel business opportunity was created for a new mode of software. Therefore, in analogy to Alfred Chandler's (1962) ‘structure follows strategy’ we introduce the notion that ‘software follows hardware’ to explain the formation of inter-firm R&D network structures in the international software industry during the last three decades of the previous century.

In that context, it is important to indicate that the international software industry can be characterized as a typical multi-product market with four main segments: independent programming services, software products consisting of enterprise solutions, mass-market software products, and finally the internet and value-added services segment (Hoch , Purkert, Lindner and Müller, 2000; Mowery, 1996).

- Independent programming services firms emerged together with the mainframe computer in the mid-1950s concentrating on custom-written software solutions for

one corporate or government customer at a time (Hoch et al., 2000; Mowery, 1996). Important companies within this segment are BSO, Cap Gemini Sogeti, CAP Group, Logica and Origin.

- IBM's unbundling decision in 1969 made an end to the hardware manufacturers' offering of free software, after which hardware suppliers would charge customers separately for software products (Steinmueller, 1996). This decision made it easier for independent software vendors to develop and commercialize their own products, which initiated the start of the enterprise solutions segment (Hoch et al., 2000). Enterprise solutions are not one-of-a-kind solutions such as found in the independent programming services segment. Rather, enterprise software solutions are pre-developed and subsequent versions are sold to multiple corporate users (Hoch et al., 2000; Mowery, 1996). Enterprise Resource Planning (ERP) software, tools for ERP installations, supply-chain management software, decision support software, call center software, inventory management software, payroll software and relationship management software are a few examples of enterprise solutions. Important companies within this segment are SAP, Baan, Oracle and Peoplesoft.
- Mass-market software products became available in the mid-1970s with the arrival of the microcomputer or the personal computer (PC) (Mowery, 1996). More in particular, the launch of the IBM PC in 1981 accelerated the emergence of PC based mass-market software. Today, there are numerous products that are part of this software segment. Examples include programming languages, operating systems, productivity applications, personal accounting software, anti-virus software, and internet browsers (Hoch et al., 2000). Well-known companies in the packaged mass-market software segment are Microsoft, Apple, Sun Microsystems, Digital Research, Corel, Lotus and WordPerfect. In addition, it is important to mention that together

with the emergence of the PC, a major sub-sector of the mass-market software industry came into existence, namely software-based home entertainment (Campbell-Kelly, 2003; Mowery, 1996).

- The last software segment is the internet and value-added services segment that emerged together with the widespread adoption of the internet. More in particular, it started in 1994 with Netscape's commercialization of browser software (Hoch et al., 2000).

According to Mowery (1996), the abovementioned division into different software sectors is logically based on distinctions in market terms and business models for each sector. Compared to the software products segment, programming services firms experience high variable costs and relatively low fixed costs, making increasing returns non-existent within that market segment. Professional services firms seem to focus their attention on specific geographical regions and they hardly ever become global market leaders (Hoch et al., 2000). Firms in the enterprise solutions segment offer products and services that need to be interdependent when selling a complete software solution to their corporate clients. Corporate software packages are often very complex and extensive and therefore require additional integration and maintenance services. As a consequence, enterprise solution firms have to deal with large development costs and high deployment costs at the customer's site. In the mass-market software products segment, companies face high fixed costs for software development while the variable costs for product copies are extremely low. Increasing returns to scale are thus very important within this market segment, which is also characterized by high market concentration (Hoch et al., 2000). Therefore, several mass-market software companies have become global market leaders in the international software industry.

In the following sections, we will first present a general overview of the historical growth pattern in R&D partnerships in the international software industry, followed by a discussion of changes in the group of leading partnering firms. Next, we discuss some major changes in the structure of R&D partnering networks and we analyze the partnering behavior of individual companies. The main data source that we use for this analysis is the MERIT-CATI database (see Appendix 1). Finally, we will present some of the main conclusions that can be drawn from this contribution in terms of historical changes in the software industry structure and their implications for changing patterns in R&D partnering.

GENERAL TRENDS IN R&D PARTNERSHIPS

During the 1970s, the number of newly established R&D partnerships in the international software industry was rather low, with an average of only two new partnerships made each year (see figure 1). An explanation for this low degree of R&D cooperation in the software industry is based on the preference for the traditional business model, centered on vertical integration and internal control of new technologies in the computer hardware industry (Bresnahan and Malerba, 1999). Leading computer companies, such as IBM, Control Data Corporation (CDC) and Sperry Rand, manufactured not only computers but they also produced the microelectronics, provided operating systems, application software and software services that came with these computers (Malerba, Nelson, Orsenigo and Winter, 1999; Weston, 2001). More in particular, internal R&D was viewed as an important strategic asset (Chesbrough, 2003) and as a result, the advantages of R&D partnerships were hardly recognized and relatively unknown within the software industry at that time.

---------- Insert figure 1 about here ----------

This changed with the growth of the PC based mass-market software segment during the 1980s. Existing market leaders experienced increased competition from many new entrants, such as Microsoft, Sun Microsystems, Lotus and WordPerfect. These companies not only innovated independently, they also made use of the research of other firms (i.e. by means of R&D partnerships) to create new products and services (Chesbrough, 2003). As a result of this increased R&D cooperation, new entrants improved their flexibility to deal with their dynamic and complex technological environment, created shorter innovation lead-times and they had the opportunity to engage in larger combined research projects (Hagedoorn, 1993).

Besides increased competition by new entrants, compatible sub-technologies, such as operating systems, microprocessors, and application software started to spread out during the PC era among a vast and diverse group of interdependent firms (Bresnahan, 2004). The compatibility of these new technologies enabled companies to collaborate further on the development and integration of a mixture of components in order to stay competitive. Openness became the norm in the computer industry and other IT industries (Methé, Toyama and Miyabe, 1997). The intensified competition in combination with the open and modular design of the PC forced leading firms to abandon traditional business models that were based on closed proprietary standards and vertical integration. As a result, they had to transform their closed vertically integrated business model into an open innovation business model (Chesbrough and Rosenbloom, 2002).

This open innovation business model can be described as the direct opposite of the closed innovation model, where internal R&D activities are transformed into internally developed products that are commercialized by the firm itself (Chesbrough, Vanhaverbeke and West, 2006). The open innovation business model, on the contrary, utilizes both external and internal ideas to create new products and services. In other words, the model is based on

the idea that knowledge is widely distributed and that every firm must identify, connect to, and leverage external knowledge sources as an essential part of its R&D activities (Chesbrough, 2003). Hence, to create a sustainable competitive advantage companies had to develop a business model that was directed towards cooperation and transcending existing firm boundaries and business system definitions. Among other things, this implied that companies began to manage their innovation process differently, by setting up inter-organizational networks consisting of multiple R&D partnerships (Leban, Lesourne, Oshima and Yakushiji, 1989; Raphael, 1989).

Consequently, we see a relatively large increase in the number of newly established R&D partnerships in the 1980s. During the early 1980s the number of R&D partnerships within the software industry increased from 7 in 1980 to 20 new agreements made in 1984. In the late 1980s the number of newly established R&D partnerships tripled again to 60 new R&D agreements made in 1989. As we will see in more detail in the next section, for many individual companies the number of newly established R&D partnerships doubled or even more than quadrupled (see table 1). The average number of R&D partnerships of the top ten most cooperating companies increased from 4.4 to 19.1 new R&D partnerships made during the period 1985-1989.

In the 1990s, client/server networking was introduced in the IT industry and this led to a drastic change in the software market structure, which at that time consisted mainly of vertically disintegrated firms (Bresnahan and Greenstein, 1999). To build these more complex computer networks, companies needed radically new software and services (Bresnahan and Malerba, 1999). Since no single firm had the capabilities to innovate in all parts and subsystems, companies started to specialize in certain market layers that were connected through open standards and interfaces (Malerba, Nelson, Orsenigo and Winter, 1999). One of the results of this specialization was an even further need for companies to

engage in R&D cooperation with other firms (Bresnahan and Malerba, 1999). This led, with the exception of a small drop in 1993, to a further increase from 60 agreements made in 1989 to over 120 new R&D partnerships that were set up in 1995. Again, at the level of individual firms this led to a substantial increase in the number of newly made R&D partnerships in software (see table 1). The average number of newly established R&D partnerships of the top ten most cooperating companies doubled to 39.3 new R&D partnerships made during the period 1990-1994.

The late 1990s were characterized by a rise in computer networking and the introduction of the largest client/server network of all, the internet (Economist, 1999; 2002). The open and modular nature of the world-wide-web and the browser technology opened up new opportunities, intensified competition and enlarged the environmental uncertainty for software firms (Hoch et al., 2000) To increase their ability to respond very quickly to the changes surrounding them, established companies had to remain open innovators and R&D partnering continued to be an important topic on the management agenda. This persistent need for cooperation is reflected in the number of newly made R&D partnerships during that period which remained comparable to the level of the period 1990-1994, with an average of 44.4 new R&D partnerships set up by the top ten most cooperating companies.

MAJOR PARTNERING COMPANIES IN THE INTERNATIONAL SOFTWARE INDUSTRY

For an impression of the role played by leading R&D partnering firms in the software industry, during various sub-periods from 1970 to 1999, we refer to table 1.

---------- Insert table 1 about here ----------

As mentioned before, during the early years of our analysis, from 1970-1979, when there were very few R&D partnerships, the most important computer hardware manufacturers controlled most of the crucial software technologies themselves and the advantages of partnerships remained relatively unidentified (Duysters, 1996; Methé et al., 1997). There were, however, a few companies in the mainframe and minicomputer segment that did participate in R&D partnerships, as shown in the listing of top ten R&D partnering companies (see table 1). Most of these firms responded in various ways to the dominant position of IBM at that time. Some companies avoided head on competition with IBM and therefore focused on niche markets. For example, NCR was mainly active in the development of retailing applications and CDC focused on scientific users in the niche market for high-performance computers (Bresnahan and Greenstein, 1999; Bresnahan and Malerba, 1999). These companies were among the most R&D partnering active companies and cooperated with each other as well as with the European firms ICL and Bull. Another niche strategy focused on software development in protected domestic markets for non-US producers (Bresnahan and Malerba, 1999). For example, European electronics firms had a weak position in the computer industry and as a consequence in the software industry as well. To diminish IBM's control over European domestic markets, governments took an active role to stimulate the feasibility of collaborative efforts in R&D. More in particular, Bull, Siemens, ICL and AEG were all sponsored by their national governments and the European Commission to increase their number of R&D partnerships. The same happened in Japan were the Ministry of International Trade and Industry (MITI) stimulated cooperation through joint R&D (Takahashi, 1996). For example, DKB was persuaded by the MITI to produce large IBM-compatible mainframes and thus the needed software as well (Jowett and Rothwell, 1986).

Computer manufacturers, active in software R&D partnering, were joined by one of the most important independent programming services firms: Cap Gemini Sogeti. At that time, hardware firms focused mainly on systems software and universal applications software (i.e. accounting, management, payroll etc.), but they offered practically no customs software (OECD, 1985). So, the presence of Cap Gemini Sogeti as a major R&D partner can be explained by the fact that this firm offered custom-written software solutions that were developed in parallel with the mainframe- and minicomputer systems software (Mowery, 1996).

The pattern that we observe for the period 1980-1984 is in some ways not that different from the previous period, 1970-1979. Several leading electronics companies from Europe, such as Siemens, Bull, Olivetti, and Philips, remained or became active R&D partners. Also in this period, R&D collaboration was encouraged by the predecessor of the EU, i.e. the EEC, this time in the area of software development and multimedia. An example of such cooperation is the multiworks project through which Olivetti, Bull, Philips, STC and others developed multimedia integrated office workstations (Mowery, 1996). In addition, we witness once more the presence of a programming services firm (Multihouse) among the firms with most R&D partnerships.

However, the pattern is different in the sense that we observe, for the first time since the invention of the microcomputer in the mid-1970s, a number of PC software companies in the listing of top R&D partnering firms. Before the emergence of the PC industry, IBM was the most successful company in the computer industry and its competitive strategy was clearly a function of the closed innovation business model (Chesbrough, 2003). This all changed with the growth of the PC based mass-market software segment. IBM was facing tremendous competitive pressures and it became clear that it could no longer supply everything itself (Chesbrough, 2003). It had to identify and combine the best knowledge

available and R&D partnerships became a major mechanism for getting access to a wide variety of external R&D sources and new technologies. This explains the number one position of IBM in the listing, while it was completely absent during the previous period. IBM was joined by Microsoft, which developed the first programming language for PCs (MBASIC), and Digital Research, the first vendor of microcomputer operating system CP/M, thereby occupying an important position in the PC software market. Finally, AT&T launched its first commercial version of UNIX, the platform for many minicomputer operating systems.

Around the second half of the 1980s, innovation in the computer industry and also in the software industry became competence-destroying, turning the competencies of incumbents more and more obsolete (Tushman and Anderson, 1986). This transformation enabled new entrants such as Sun Microsystems to become a successful innovator (Mazzucato, 2002) that also played a leading role in setting up a variety of R&D partnerships. Several professional services firms, a number of computer hardware manufacturers, and one electronics firm (Cap Gemini Sogeti, BSO, Volmac, Philips, DEC and Hewlett-Packard) are also part of the listing of firms with most R&D partnerships.

The importance of the PC software market became more and more visible in inter-firm R&D partnering during the 1990s (Campbell-Kelly, 2003). Based on economies of increasing returns, the market became concentrated and major US companies such as IBM, Microsoft, Hewlett-Packard, Sun Microsystems, DEC, AT&T, Xerox, and Apple dominated the industry. This is clearly illustrated in the list of firms with most R&D partnerships, which consists completely of US companies.

Besides the importance of the PC software segment, we also observe the emergence of the computer network segment (Bresnahan, 1998) and the development of new software and services (Bresnahan and Malerba, 1999). Oracle and Novell were among the first

companies active in networking software and they profited from several of the new opportunities generated by computer networks. This illustrates the evolvement of the network era in which, as we will demonstrate in the next section, the new entrants became nodal players in the R&D network with numerous ties to other participants.

Comparable to the PC era, an important feature of the network era was that no single firm had the capabilities to innovate in all subsystems and companies started to specialize even further in certain market layers that were connected through open standards and interfaces (Malerba et al., 1999). One of the results of this specialization was the ever-increasing need for companies to engage in R&D cooperation with other firms (Bresnahan and Malerba, 1999; Leban et al., 1989; Raphael, 1989). Consequently, the most important companies also entered into very large numbers of R&D partnerships. IBM for example formed 75 new R&D partnerships during the period 1990-1994, compared with only 25 R&D partnerships in the previous period (see table 1).

As mentioned in the above, the period 1995-1999 was characterized by the introduction of the internet, the commercialization of the browser by Netscape and parallel opportunities for joint technology development (Bresnahan, 2004; Chesbrough, 2003; Economist, 1999, 2002), which explains the presence of Netscape in the listing of top ten partnering companies. In addition, throughout the second half of the 1990s, companies such as IBM, Microsoft, Hewlett-Packard, Sun-Microsystems, Intel, Motorola, Siemens, and Oracle remained important mediators of numerous knowledge flows between partnering companies. Finally, an explanation for the presence of Cisco lies in the fact that this company experienced intensified competitive pressures during the mid-1990s. As a reaction, Cisco shifted from a closed innovation model to an open innovation model with a strong focus on partnerships (Yost, 2005).

THE STRUCTURE OF INTER-FIRM R&D NETWORKS

We now turn to an overview of major historical changes in the structure of R&D networks of the most active firms, examining both network-level characteristics and partnering behavior at the level of individual firms.[1] Figures 2-6 give us a graphical representation of the networks of newly established R&D partnerships in the computer industry during the periods 1970-1979, 1980-1984, 1985-1989, 1990-1994, 1995-1999, for which we use a non-metric multidimensional scaling (MDS) technique. MDS is a data reduction procedure somewhat comparable to principal component analysis and other factor-analytical methods. One of the main advantages of MDS is that it can usually, but not necessarily, fit an appropriate model in a two-dimensional picture. Particularly, MDS offers a scaling of similarity data into points lying in an X-dimensional space. The purpose of this method is to provide coordinates for these points in such a way that distances between pairs of points fit as closely as possible to the observed similarities. In order to facilitate interpretation, the solution is given in two dimensions, provided that the fit of the model is acceptable. A stress value indicates the goodness-of-fit of the configuration as this measures the proportion of the variance of the disparities that is accounted for by the MDS model, implying that lower values indicate a better goodness of fit (Hair, Anderson, Tatham, and Black, 1998). For all MDS solutions presented in this paper Kruskal's stress values (Kruskal and Wish, 1978) range from 0.001 (excellent) for the period 1970-1979 to 0.039 (excellent) for the period 1995-1999.

[1] There are a large number of companies with only one or very few R&D partnerships made during the more recent periods. This creates some restrictions with regard to our MDS-based network graphs. Consequently, our analysis of R&D networks established during each sub-period concentrates on the twenty leading partnering firms and their partners.

Using the network visualization software tool Najojo (see Appendix II), we enhance the interpretability of these MDS pictures, first, by adding company labels to the dots, and, second, by drawing lines of different styles and thickness between pairs of firms with varying degrees of partnering intensity. Dotted lines represent one R&D partnership between companies, whereas solid lines indicate 2 or 3 partnerships. Bold solid lines indicate 4 or more R&D partnerships between companies.

Inter-firm R&D networks, 1970-1979

The period 1970-1979 (see figure 2) is characterized by a sparse and disconnected network consisting of 31 firms in total. More in particular, the network at that time consists of three isolated R&D clusters and six one-on-one R&D partnerships. The largest research cluster situated at the right hand side of figure 2 is partly dominated by some of Europe's leading electronics companies of that period (ICL from Britain, AEG, Siemens, and Nixdorf from Germany and Bull from France). The lack of a competitive European computer hardware industry in combination with an early entry by successful American software firms in Europe gave the European firms a weak position in the software industry (Campbell-Kelly, 1995). As briefly mentioned in the above, in a reaction to this weak position, several governments used a 'national champion' strategy in the hope of diminishing US control, or more specifically IBM's control, over European domestic markets. Encouraged by the European Commission, the leading electronics companies all became members of the so-called Round Table and studied the feasibility of European collaborative efforts in R&D (Jowett and Rothwell, 1986). Although public policies' attention at that time was mainly focused on mainframes and semiconductors (Torissi, 1998), it also led to R&D cooperation by these companies in software technologies, as shown in figure 2.

---------- Insert figure 2 about here ----------

More in particular, at that time European firms had the highest chance of creating a sustainable competitive advantage in those areas that were protected from US competition by security considerations or by the availability of unique local knowledge. So, European firms played an important role in the defense-software sector and niches such as financial systems and retailing (Campbell-Kelly, 1995). This is probably also the reason why major European firms such as ICL, Bull and Siemens cooperated with the French company Intertechnique SA, which was active in the aerospace & defense sector and NCR, a specialized software services firm mainly active in the development of retailing applications (Bresnahan and Malerba, 1999). Besides NCR, the European firms were joined by three other US firms (Engineering Numerics, CDC and GTE).

The second large cluster of intra-European cooperation, at the lower left hand side of figure 2, consisted of three large software-using firms (Nationale Nederlanden, Akzo and PTT Telecom) and Cap Gemini Sogeti and CAP Group, two professional services companies that were among the early independent software vendors (Hoch, et al., 2000).

A third, somewhat smaller cluster present in this period was centered around several of the largest keiretsus of Japan (DKB, Sumitomo and Hitachi) and TRW. TRW is part of the Japanese dominated cluster because it created a joint venture with Fujitsu (DKB) to market Japanese computers and jointly developed software for the US market (Jowett and Rothwell, 1986). With respect to Japanese computer manufacturers, MITI made it mandatory in 1971 for these companies to organize themselves in three major groups to stimulate cooperation through joint R&D (Takahashi, 1996). Within the software industry the activities of these computer manufacturers were focused mainly on the development of customized software for mainframe computers (Baba, Takai and Mizuta, 1996). This is no surprise, given the fact that the Hitachi-DKB group (DKB is the parent company of Fujitsu) was persuaded by the MITI

to produce large IBM-compatible mainframes as well as the software for these systems (Jowett and Rothwell, 1986). Apart from mainframe software, the competitive advantage of Japan was highest in the development of custom software solutions (Campbell-Kelly, 1995; Mowery, 1999). More in particular, Japan's most successful software developments in the late 1970s were embedded programs that were installed in multimedia entertainment products (Jowett and Rothwell, 1986). The partnership between Sony and CBS is an example of such cooperation in the multimedia entertainment software industry and more in particular the music software business (Campbell-Kelly, 2003).

Finally, we can distinguish some large integrated hardware companies that also provided their own operating systems, application software, and services in several one-on-one R&D partnerships. For example, IBM was cooperating with the Fuyo Group from Japan and Sperry was cooperating with Unify from the US.

Inter-firm R&D networks, 1980-1984

Also for the period 1980-1984 (see figure 3) we see a sparse R&D network where major companies such as IBM, NEC (Sumitomo), Siemens, Hitachi, and Olivetti, that all belong to the top fifteen software suppliers of that era (Campbell-Kelly, 2003), were cooperating within the context of one relatively large research cluster and six smaller ones. Many of the small R&D clusters were organized around three or four partners at the most and in almost each cluster one large integrated hardware firm was present. For example, Sperry was cooperating with the professional services firm Multihouse. In addition, Honeywell had an R&D partnership with Ericsson, CDC cooperated with Chrysler and Elbit, and Hitachi cooperated with Applied Data Research and Telex. Also, with the exception of Microsoft and Olivetti, the majority of firms were connected to one specific partner through no more than one R&D partnership.

Besides the presence of computer hardware manufacturers, we witness for the first time since the invention of the microcomputer in the mid-1970s, a number of PC software companies such as Lotus, Microsoft and Digital Research. In 1983, Lotus introduced its 1-2-3 spreadsheet and by the end of the period it was the leading PC software company in terms of revenues (Campbell-Kelly, 2003). Microsoft and Digital Research laid the foundation for the PC software market by developing an operating system and programming language for the microcomputer (Campbell-Kelly, 2003).

---------- Insert figure 3 about here ----------

When taking a closer look at the left hand side of figure 3, we notice that IBM occupied a central position within the R&D network. As explained in the previous section, IBM gradually became more of an assembler of PCs that purchased a large share of the needed components and software on the market (Malerba et al., 1999). The fact that IBM combined a multitude of software packages, jointly developed with other companies, and offered them to the customer as one piece explains the central position of IBM in the network (Campbell-Kelly, 2003). In that context, IBM undertook R&D partnerships with a relatively large number of companies such as Artificial Intelligence, Comshare, Eastman Kodak, Mitsubishi, Cosmo 80, Merrill Lynch, CSK, Microsoft, AT&T, and Digital Research.

Besides IBM, Microsoft, AT&T, and Digital Research were also significant conduits of knowledge between other network participants. Digital Research occupied a central position as an important player in the operating system software market and was linked to essential partners such as IBM, AT&T and NEC (Sumitomo), the latter being the dominant firm in the PC industry in Japan. Microsoft performed a very important bridge function with

its joint R&D on programming languages, connecting the left hand side of the cluster (US and Japanese firms) with the right hand side (European firms).

At the right hand side of figure 3 we witness some of Europe's leading electronics champions such as Siemens from Germany, Bull from France, Olivetti from Italy and Philips from the Netherlands. During the early years of the 1980s, several European countries launched a number of national policies and programs to stimulate the overall information-technology sector (Mowery, 1996), which consists of several sub-sectors such as computers, telecom, semiconductors, industrial automation and software (Hagedoorn, 2002). In contrast to the policies of the 1970s, which mainly focused on computers and semiconductors, the programs of the 1980s included extensive support for software development, driven by the increasing importance of software and services in information technology.

This significant shift in attention forced the European electronics firms to focus their strategy and core activities on software and services as well. Besides the national policies, the EEC started with several European IT support programs, such as ESPRIT and Eureka which involved Siemens, Bull and Olivetti. In addition, R&D collaboration was encouraged by the EEC in the area of multimedia (video, voice, sound & graphics), such as the multiworks project through which Olivetti, Bull, Philips, STC and others developed multimedia integrated office workstations (Mowery, 1996). Of the European firms, especially Siemens and Olivetti focused a large share of their resources on software products and services by, amongst other things, R&D cooperation with Microsoft.

Inter-firm R&D networks, 1985-1989

The PC industry developed further in the period 1985-1989, from a small number of firms that assembled machines, supplied add-on parts, wrote software and provided services to a significant sub-segment within the computer industry (Langlois, 1990) and also the software industry. In addition, sub-technologies for the PC such as operating systems (OS) technology,

microprocessor (MPU) technology and application software started to spread out among interdependent firms (Methé et al., 1997). For example, Hewlett-Packard concentrated on servers, peripherals, and software services, Sun Microsystems on workstations and related software, Intel and Motorola on the microprocessor chip, AT&T on operating systems for the minicomputer and Microsoft dominated the PC operating systems market. However, the need for software integration of the different sub-technologies in combination with further technological developments resulted in increased R&D cooperation among the central players (Methé et al., 1997; Langlois, 1990).

Consequently, we observe one relatively large R&D network during the period 1985-1989, characterized by numerous direct and indirect ties of central partnering firms that were often engaged in two or more R&D partnerships (see figure 4). Examples of partners with repeated ties include Hewlett-Packard and Microsoft, IBM and Microsoft, AT&T and Microsoft, Apple and Microsoft and Sun Microsystems and AT&T. More in particular, Sun Microsystems and AT&T collaborated extensively to develop and market several UNIX related products such as the software system Vrelease4 (Sun Microsystems, 2007). In addition, Sunsoft (a subsidiary of Sun Microsystems) and Microsoft developed operating systems for the Unix environment, which by that time was available for many platforms (not only the minicomputer) (Campbell-Kelly, 2003).

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The growth of the PC segment in the mid-1980s became apparent by the presence of IBM, Apple and several mass-market software product firms such as Microsoft, Lotus and WordPerfect. When IBM launched its PC, it approached Microsoft and Digital Research for the development of operating systems and software, since they were the industry leaders in

systems software for PCs (Campbell-Kelly, 2003). Digital Research let the opportunity pass and Microsoft produced an operating system (MS-DOS) in addition to the programming languages (MBASIC). This explains the central position of Microsoft in the network of 1985-1989 and the absence of Digital Research, despite its central position in the previous period. Besides the intensive cooperation with IBM, Microsoft also worked on licensed versions of AT&T's UNIX and launched several products for Apple's new computer, the Macintosh.

With respect to the Japanese firms in the network, it clearly shows that they were hardly present and those firms that were present (i.e. Mitsubishi, Sharp, Matsushita, Shimuzo, Sumitomo, Hitachi and Fuyo) were almost all involved in R&D cooperation with DKB, the parent company of Fujitsu. As mentioned before, Japan was only successful in its protected mainframe software market (Campbell-Kelly, 1995; Mowery, 1999). In the mainframes segment, Fujitsu (DKB) did not use IBM software but developed its own operating system and developed software with its Japanese partners. Given its strong position in computer hardware and systems, it also became one of the world’s leading software suppliers by the mid 1980s (Campbell-Kelly, 2003).

At the top left-hand side of figure 4 we notice several (mostly European) professional software services firms such as, Cap Gemini, Cap-Group, BSO, Volmac, Multihouse and CMG, located closely together. This part of the network clearly illustrates the specialization of the European software industry in custom-made software and services. In addition, European electronic firms such as Siemens, Olivetti, Nixdorf, Philips and Bull are located nearby. Research by Mowery (1996) shows that especially software firms in Western-Europe assigned high importance to joint R&D with competitors as a significant source of knowledge acquisition that led to increased innovation. In addition, as mentioned before, increasing returns were non-existent within the programming services segment and as a result professional software services firms concentrated their efforts mostly within one particular

geographical area (Hoch et al., 2000). This explains the large presence and intensive cooperation of professional services firms and electronics firms originating in Western Europe (in particular France, Germany, Italy, the Netherlands, and the UK).

At the right hand side of the network we find numerous US network participants with a strong focus on aerospace and defense related software services, such as TRW, Boeing Aerospace, General Dynamics, Allied-Signal, McDonell-Douglas, Lockheed, Martin-Marietta, Northrop, Grumman, and United Technologies. As in most countries, the aerospace and defense industry in the US is mainly a cooperation of public institutions (Department of Defense and NASA) and private companies. In view of that, most of the above mentioned companies acted as contractors for the US government and cooperated closely with each other in R&D. Especially long lead times, high risks and the large amount of R&D investments required to develop new products and services within this specific market segment were driving the spate of partnering activity (Selwyn, 1992).

Interestingly, each of the Triad regions (Europe, North America and Asia) occupied a brokerage position between the aerospace and defense cluster and the general software cluster (mainly programming services and mass-market software products). Plessy, a UK-based electronics, defense and telecommunications company represented the European linkage. Sumitomo (NEC) represented the Asian linkage and Interleaf, a company that produced technical publishing software products, represented the US linkage. In addition, Hewlett-Packard and AT&T had direct linkages with the aerospace and defense research cluster. Finally, we witness the first presence of two enterprise solutions firms in the overall network of R&D partnerships in the international software industry, namely Baan and Oracle.

Inter-firm R&D networks, 1990-1994

The importance of the PC software mass-market became more and more visible in the R&D network of the 1990s. As mentioned before, companies in that specific software segment

have to deal with high fixed costs for software development while the variable costs for product copies are very low (Hoch et al., 2000). Economies of increasing returns are thus very important within this market segment, leading to a high concentration and a winner-takes-it-all market (Campbell-Kelly, 2003). Since European and Japanese firms had only limited success in the PC industry, that market was dominated by major US companies such as IBM, Microsoft, HP, Sun Microsystems, Apple and Compaq. As we will see below, the same group of companies also occupied central positions in the PC software R&D network.

Besides the importance of the PC software segment, we witness a change in the structure of the computer industry in the early 1990s that also affects other parts of the software industry. Within the computer industry, networked computers (based on PC hardware components) were replacing the dedicated hardware installations from the mainframe and minicomputer and a clear growth in the computer network segment emerged as a results of this (Bresnahan, 1998). Within the network segment, existing types of small computer systems were linked to build more complex computer networks, which led to the development of new software and services (Bresnahan and Malerba, 1999). Comparable to the PC era in the 1980s, no single firm had the capabilities to innovate in all parts and subsystems and companies started to specialize in certain market layers that were connected through open standards and interfaces (Malerba et al., 1999). One of the results of this specialization was the ever-increasing need for companies to engage in R&D cooperation with other firms (Bresnahan and Malerba, 1999; Leban et al., 1989; Raphael, 1989).

As a result, the software R&D network of the period 1990-1994 became relatively large and even more dense than the network of the 1980s (see figure 5). Within the microcomputer segment, Compaq, IBM and HP were the leading PC vendors (Dedrick and Kraemer, 1999) but Microsoft became the dominant player in the early 1990s, based on a new version of Microsoft's operating system (Windows 3.0) and some years later Windows

Office. Apart from Microsoft, which engaged in a large number of R&D partnerships, Novell occupied a central position in the R&D network in the software industry. Novell was one of the first companies active in networking software and Local Area Networking (LAN), an industry sector that began to take off in the early 1990s (Yost, 2005). More in particular, in 1989 Novell launched a multi-thread LAN system that worked on all the important operating systems, including IBM's OS/2, AT&T's Unix and Apple's Macintosh (Hoch et al., 2000). R&D partnerships were instrumental in developing software for all these different operating systems.

Next to the enlarged concentration of PC firms in combination with a changing software structure, an outstanding feature of the network was the large number of repeated partnerships carried out by most of the important players. For example, Apple and IBM started multiple partnerships with each other during the early 1990s (Hagedoorn et al., 2001). In 1993, IBM and Apple entered into a joint development agreement with Novell to develop so-called object linking and embedding (OLE) software. In 1994, IBM, Apple, AT&T and Siemens undertook joint R&D for the development of open, cross-platform specifications in computer-telephone-personal data interchange. In the same year, IBM and Apple developed an on-line architecture for interactive multimedia together with Scientific Atlanta. These are just a few examples of the relatively large increase in repeated ties, as shown in figure 5.

---------- Insert figure 5 about here ----------

Besides the PC mass-market software firms, we also witness several important players of the enterprise solutions segment in the network of the early 1990s, such as Dun & Bradstreet, Oracle, Baan and SAP. In the 1990s, Dun & Bradstreet was the largest vendor of mainframe business application software. Oracle was the dominant firm in the relational

database software sector for the client-server environment, an environment where network architecture separates the client (i.e. an application) from the server, while IBM continued to dominate the same sector in the mainframe market (Campbell-Kelly, 2003). Baan and SAP were the largest players in the ERP software sector. ERP took off in the early 1990s when clients invested in one comprehensive and integrated business solution instead of a bundle of separate corporate packages (Campbell-Kelly, 2003). Of all the enterprise solutions firms, Oracle occupied the most central place in the R&D network, comparable to the central position of Novell in the operating systems segment. Oracle profited from the fact that also in the enterprise solutions, industry computer networks were replacing hardware installations and it entered into a large number of R&D partnerships to develop new software.

Interestingly, the European professional services firms are no longer present in the R&D network of the early 1990s. An explanation is found in the fact that services of independent programming firms had been developed together with the mainframe computer suppliers. These mainframe computers were now replaced by network computers, which were in need of a different type of software solutions. The presence of European electronics and IT firms was diminishing as well, with the exception of Siemens, Olivetti and Bull. Siemens and Olivetti strengthened their position in the R&D network of the 1990s as key players. Bull increased its involvement in joint software and services development in the early 1990s, especially in Unix applications (Mowery, 1996).

Finally, at the top right-hand side of the overall R&D network we see a ‘mixed’ pattern of cooperation between companies from diverse industries such as aerospace and defense related software services firms (i.e. Boeing Aerospace and Lockheed), car manufacturers (i.e. Chrysler, Ford and General Motors) and oil companies (i.e. Exxon and Standard Oil of Indiana). Xerox played an important role in this sub-network as well through its various R&D partnerships with amongst others Sun Microsystems and AT&T.

Inter-firm R&D networks, 1995-1999

The period 1995-1999 is characterized by a rise in computer networking and the world-wide diffusion of the internet. Two factors were very relevant in the commercialization of the internet as a mass-market technology, the world wide web and the (web) browser (Bresnahan, 2004). Netscape was the first company that commercialized the browser, which was a modular component designed to run on all sorts of existing PC operating systems such as Windows, Macintosh and Unix (Bresnahan, 2004). The introduction of the internet created various new software applications and services opportunities for networking firms but it also led to increased competition for established firms (Hoch et al., 2000; Yosh, 2005). An example of such a new service opportunity was the implementation of ERP software. In the early days, ERP applications linked relatively small parts of a company's operations. However, with the rise of the internet, these parts could increase in size and this made it possible for firms to tie together geographically dispersed divisions that were previously separated (Economist, 1999, 2002). An example of a firm, which profited from these new opportunities offered by the internet, is Sun Microsystems that introduced a new software application development platform, called Java (Bresnahan, 2004).

A further interesting aspect of this period was the fact that the boundaries between various market segments (professional services, enterprise solutions and mass-market products) started to blur due to the unique characteristics of the internet, making it possible for firms with strengths in one sector to diversify into one of the other sectors (Hoch et al., 2000). Finally, more than in the previous period, during the period 1995-1999 companies had to deal with the 'coexistent challenge' (Hoch et al., 2000: 270). Numerous platforms, operating systems, programming languages and de facto standards coexisted next to each other, increasing the level of technological complexity of various software products and services. In sum, intensified competition in combination with lower entry barriers and vast

technological complexity increased the need for software companies to cooperate in order to survive.

Consequently, a large and dense R&D network of research partners, which were all connected to each other by numerous direct and indirect ties, distinguishes the period 1995-1999 (see figure 6). One of the most interesting aspects of this period is the entry of Netscape which created multiple R&D ties with several of the other important network players. Netscape was such an attractive partner because it was the first company that commercialized the browser and in addition played a critical role in the commercializing of the hypertext markup language (HTML) and the hypertext transfer protocols (http) for the browser (Bresnahan, 2004; Chesbrough, 2003). Cisco, another new player in the overall R&D network, entered the network of R&D partnerships because it provided a wide range of end-to-end networking solutions and benefited from the increased demand for networking technology with the internet (Yost, 2005).

---------- Insert figure 6 about here ----------

Several of the largest players in the enterprise solutions segment were also present in the network of the second half of the 1990s. SAP and Baan from Europe and Peoplesoft from the US were mainly collaborating with others in the ERP software sector. Oracle benefited from an increased interest in networking solutions, specifically in the area of relational database systems, while it set up various R&D partnerships.

Within the PC mass-market software segment, US market leaders such as Sun-Microsystems, Apple, IBM, Intel, Compaq, Hewlett-Packard, Motorola, Novell and Microsoft were still occupying central positions within the software R&D network. This can be explained by the fact that despite increased competition, the widespread use of the internet

did not lead to a wave of creative destruction in the PC business (Bresnahan, 2004). Mass-market software firms remained important players in the software industry and cooperated intensively with each other. For example, in 1996, Apple, IBM, Sun Microsystems, Motorola, Netscape, Novell, BCE, and Silicon Graphics together developed a platform independent cryptography set of application programming interfaces (PICAs) (Hagedoorn et al., 2001). Finally, at the left hand side of figure 6 we see three important Japanese players in the videogame market, Nintendo, Sega and Sony, illustrating the interest of Japanese companies in the recreational software industry.

CONCLUSIONS

A major conclusion from the above is that the understanding of the historical evolution of inter-firm R&D partnering and R&D networks in the international software industry cannot be seen separately from some important developments in the computer industry, i.e. software followed hardware. Before the 1970s, computer manufacturers produced software as a complementary product, expecting that a larger availability of software would lead to an increase in hardware sales (Steinmueller, 1996). The unbundling decision of IBM in 1969 and Intel's invention of the microprocessor, followed by the introduction of new types of computers (supercomputer and minicomputer), boosted the exploitation of software (Bresnahan and Greenstein, 1999; Campbell-Kelly, 1995; Duysters, 1996). Yet, the wide-ranging need for specialized software created a highly fragmented industry. This fragmentation led to a very opaque market with high information asymmetry for software users, which helped to sustain the important position of large vertically integrated computer manufacturers within the software industry (Steinmueller, 1996). However, during the PC era in the mid-1980s and the networking era in the 1990s, companies started to experience enlarged technological complexity, a widespread heterogeneity of potential technologies,

increased uncertainty, lower entry barriers and shorter product life cycles (Hagedoorn, 1993; Hoch et al., 2000; Mowery, 1988, OECD, 1992). As a result, most companies were unable to stay up-to-date with the latest technological developments solely by relying on their internal R&D. To stay innovative and create a sustainable competitive advantage they increasingly had to adopt open innovation business models, e.g. through engaging in a portfolio of flexible R&D partnerships.

This transition from closed to open innovation business models in combination with increased R&D cooperation indicates a change in the specific structures of inter-firm R&D networks. While the international software industry of the 1970s and early 1980s is characterized by relatively sparse and disconnected networks, the industry in the mid-1980s and 1990s shows a dense network structure whereby most participants are either directly or indirectly connected to each other. In congruence with the above mentioned conversion, the dominance of the large established hardware producers and professional services firms within the R&D network diminished during the period of our analysis, while new entrants such as Microsoft developed into dominant players with nodal positions through multiple partnerships. Finally, when the PC industry emerged from the pre-existing markets for mainframe computers and minicomputers, U.S. companies also became the most dominant players in networks of software R&D partnerships established during the 1990s.

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APPENDIX 1: DATA

For our analysis, we make use of data on inter-firm R&D partnerships, taken from the MERIT-Cooperative Agreements and Technology Indicators (CATI) information system (see Hagedoorn, 1993). This databank contains information on nearly 10,000 cooperative agreements in various sectors, ranging from high technology sectors, such as information technology and biotechnology, to less technology intensive sectors, such as chemicals and heavy electrical equipment. Cooperative agreements are defined as mutual interests between independent industrial partners that are not linked through majority ownership. In the CATI database, only those agreements are being recorded that involve either a technology transfer or some form of jointly undertaken R&D. Information is also collected on joint ventures in which new technology is received from at least one of the partners, or on joint ventures having some R&D program. Other types of agreements such as production and marketing partnerships are not included. Agreements formed between companies and governmental or academic institutions are generally not included in the database unless they involve at least two commercial companies.

The current paper focuses on those partnerships that were established in the period 1970-1999. In the CATI databank more than 2500 global R&D agreements in the software industry involving 982 firms were recorded during this time frame. Our data include equity agreements, joint ventures, as well as non-equity partnerships that consist of joint R&D pacts and joint development agreements. The data excludes agreements that are established within the context of national and international, government sponsored, R&D cost-sharing programs. For our purpose, the most relevant information for each partnership is the number of companies involved, their names as well as the year in which the agreement was established.

APPENDIX 2: NAJOJO

To facilitate our analysis and visualize the different R&D networks that have come into existence during each of the five-year sub-periods examined in this paper, we make use of our own network visualization software tool Najojo. As existing visualization software has serious difficulties in handling this kind of large-sized research networks, we developed our own software. This tool, capable of visualizing large, dense networks involving more than 500 companies, was ultimately created by Johan Willekens.

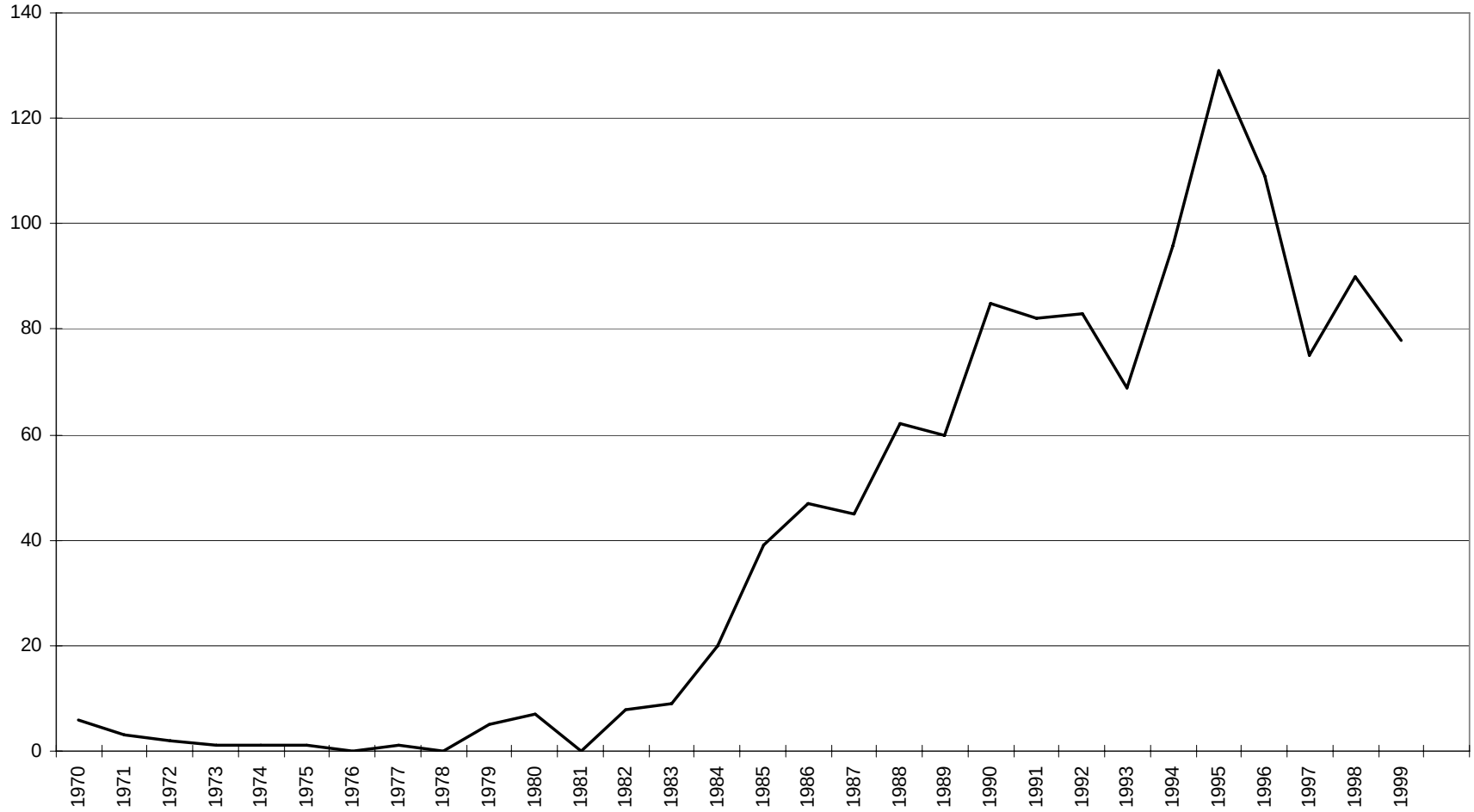
There are two separate input (text) files underlying the generation of networks in Najojo: one file holding the MDS coordinates for each of the individual companies participating in the network and one file holding all unique company pairs and their numbers of research partnerships. On the basis of the first input file, Najojo determines whether the particular network will be visualized in landscape (see for example figures 2-6) or portrait orientation. As a second step in the visualization process, the tool divides up the landscape in an X number of points. The firm coordinates held by the first input file are then mapped onto these points and visualized as dots. While creating this scatter plot, the program makes sure that the relations between dots are held constant and that dots belonging to different companies do not overlap. Thirdly, company labels are placed with the dots in such a way that they do not overlap with other labels or dots. Najojo variably determines the font size of company labels depending on network density and the number of companies participating in the network. Fourthly, on the basis of the second input file, Najojo visualizes the total number of partnerships entered into by all unique company pairs making up the network. The tool first identifies both research partners, i.e. the beginning and ending dots, and subsequently draws polybezier lines between these dots, making sure that these lines do not cross dots belonging to companies that are not part of the partnership. The type of line (dotted, solid, thick solid) can be determined by the user.

Table 1. A comparison of the top ten firms with the most R&D partnerships in software in 1970-79, 80-84, 85-89, 90-94, and 95-99 (numbers in brackets).

1970-79		**1980-84**		**1985-89**		**1990-94**		**1995-99**	
1. Bull	(8)	IBM	(10)	IBM	(25)	IBM	(75)	Microsoft	(82)
2. Siemens	(7)	Digital Research	(5)	Microsoft	(23)	Hewlett-Packard	(63)	IBM	(73)
3. ICL	(6)	Olivetti	(4)	Hewlett-Packard	(21)	Microsoft	(41)	Hewlett-Packard	(54)
4. CDC	(6)	Philips	(4)	DEC	(21)	Sun Microsystems	(41)	Sun Microsystems	(50)
5. AEG	(5)	Siemens	(4)	Sun Microsystems	(21)	DEC	(35)	Netscape	(40)
6. Cap Gemini Sogeti	(4)	Microsoft	(4)	Philips	(20)	AT&T	(31)	Intel	(36)
7. NCR	(4)	AT&T	(4)	AT&T	(16)	Novell	(30)	Motorola	(30)
8. DKB	(3)	STC	(3)	Cap Gemini Sogeti	(15)	Apple	(29)	Siemens	(28)
9. -		Bull	(3)	BSO	(15)	Oracle	(28)	Cisco	(26)
10. -		Multihouse	(3)	Volmac	(14)	Xerox	(20)	Oracle	(25)

Source: MERIT-CATI databank.

Figure 1. Growth of numbers of newly established R&D partnerships in the software industry, 1970-1999; *source*: MERIT-CATI.



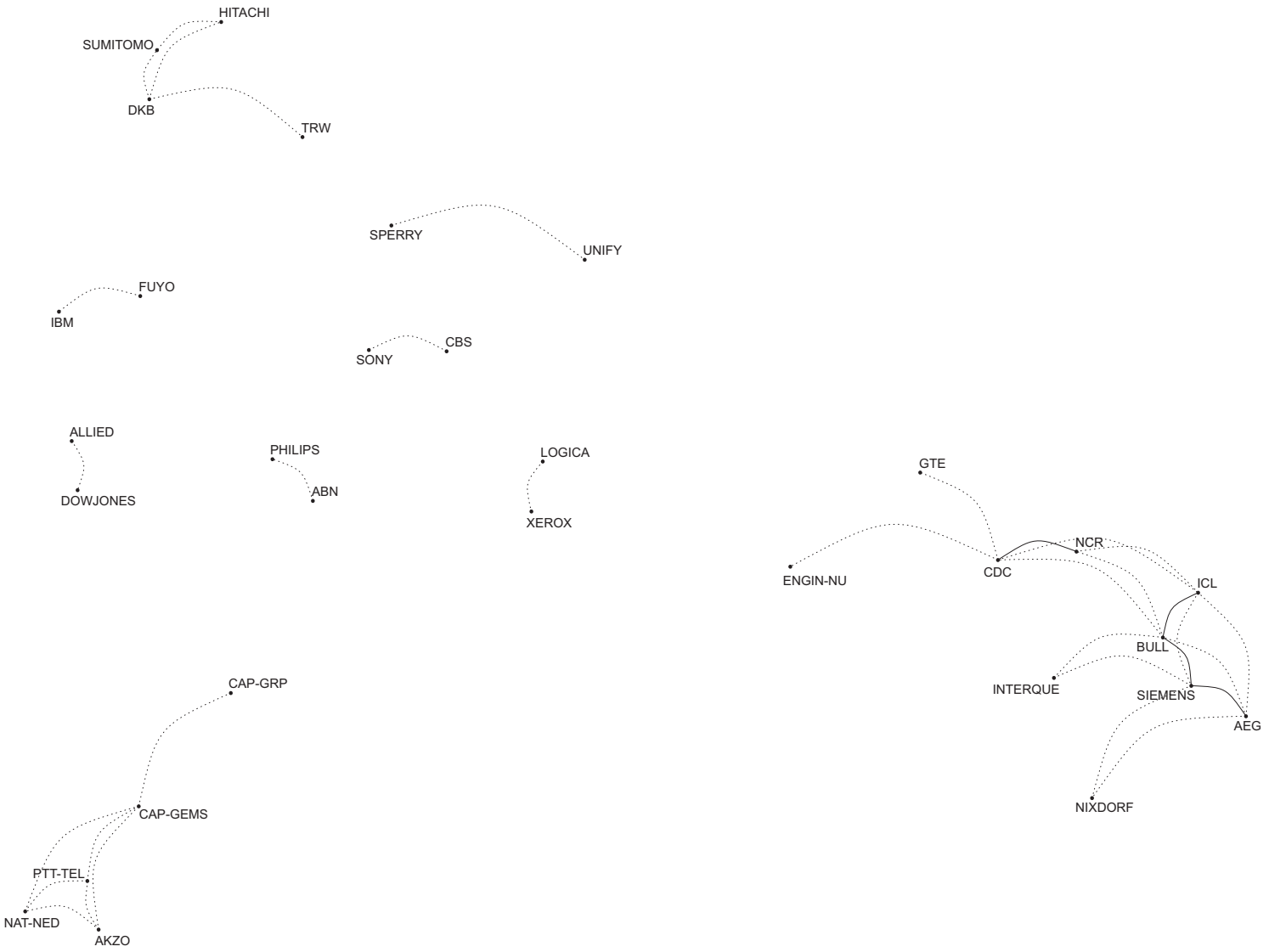


Figure 2. Inter-firm R&D partnerships amongst cooperating companies in software, 1970-79; *source:* MERIT-CATI.

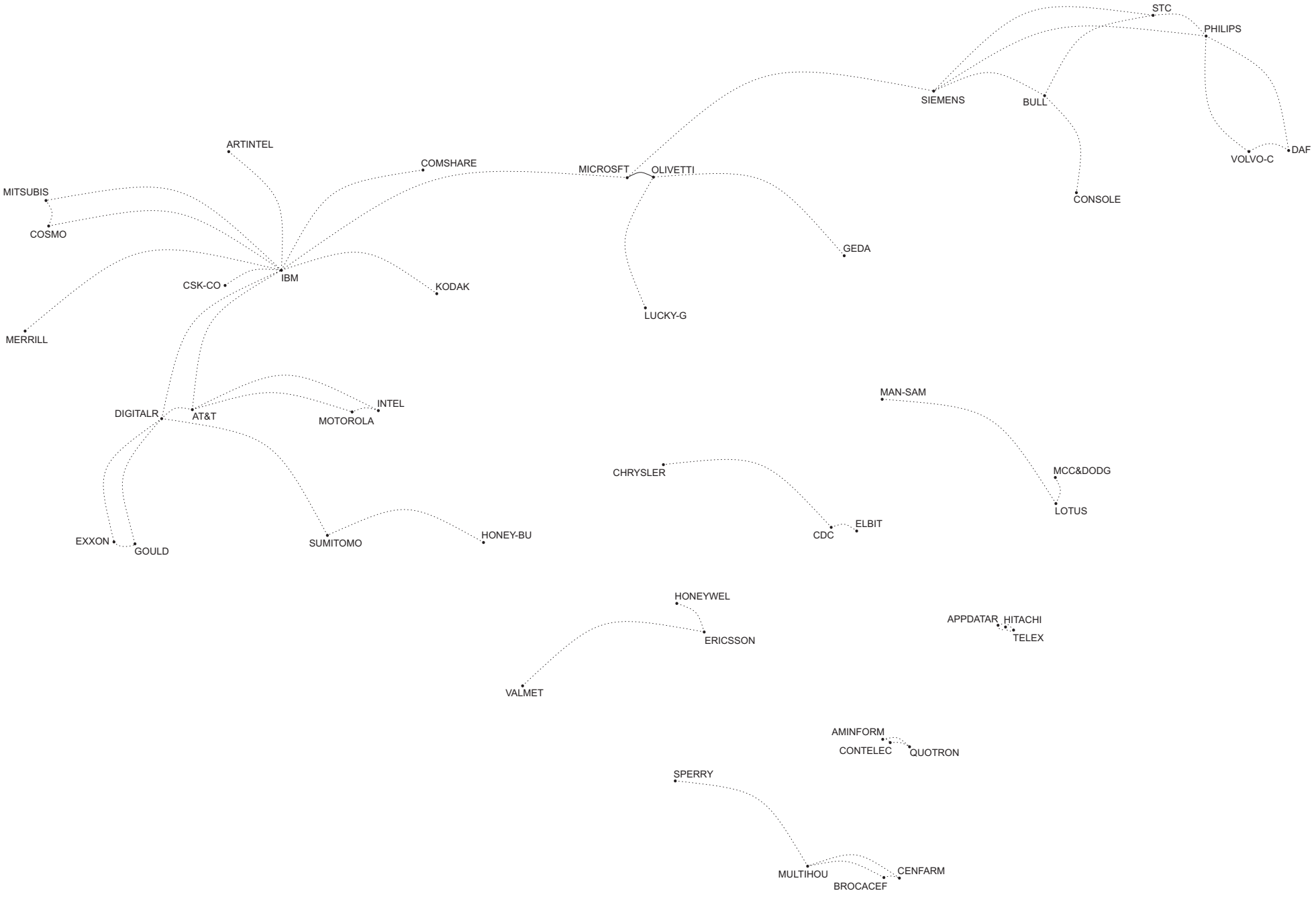


Figure 3. Inter-firm R&D partnerships amongst cooperating companies in software, 1980-84; *source:* MERIT-CATI.

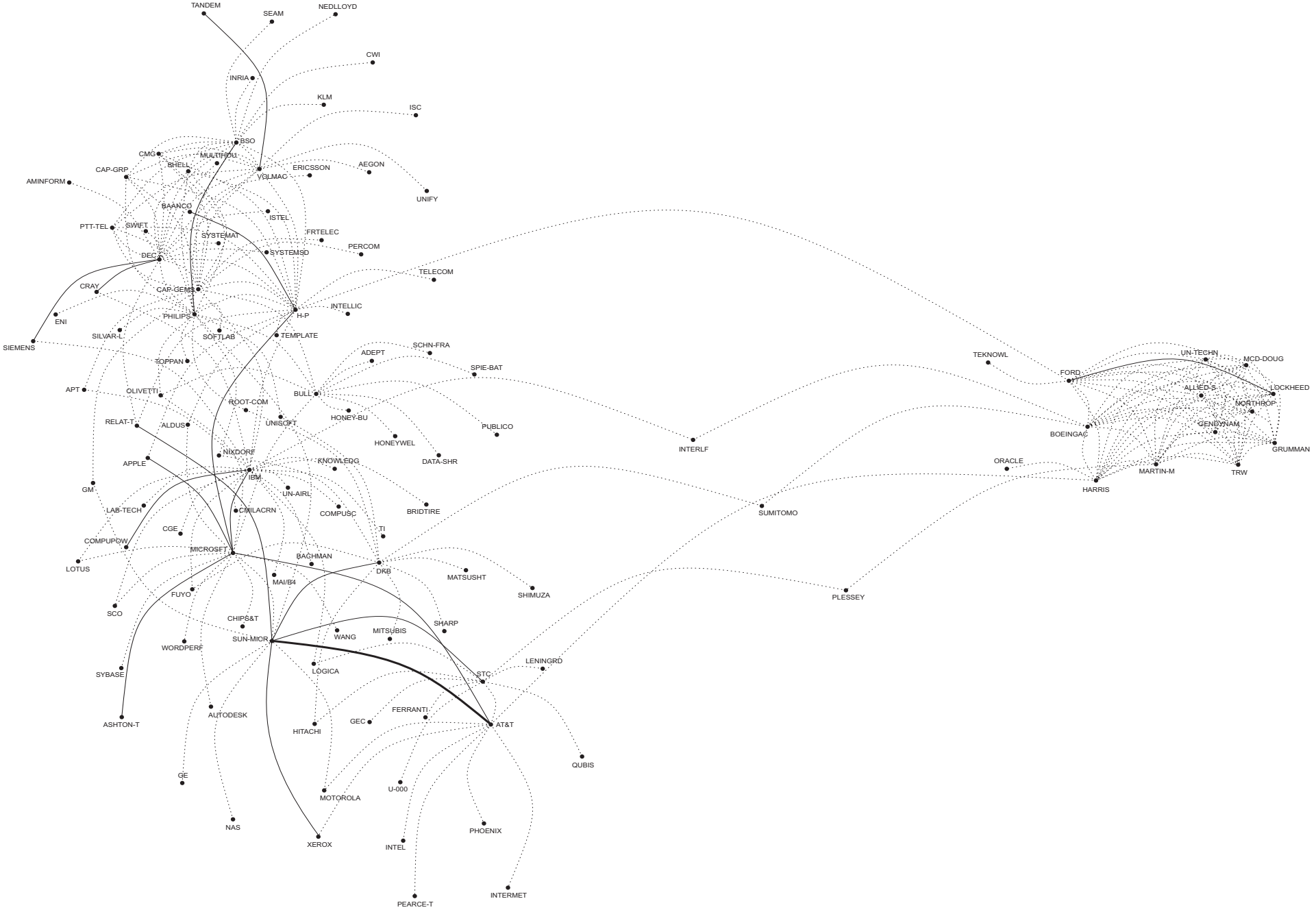


Figure 4. Inter-firm R&D partnerships amongst cooperating companies in software, 1985-89; *source:* MERIT-CATI.

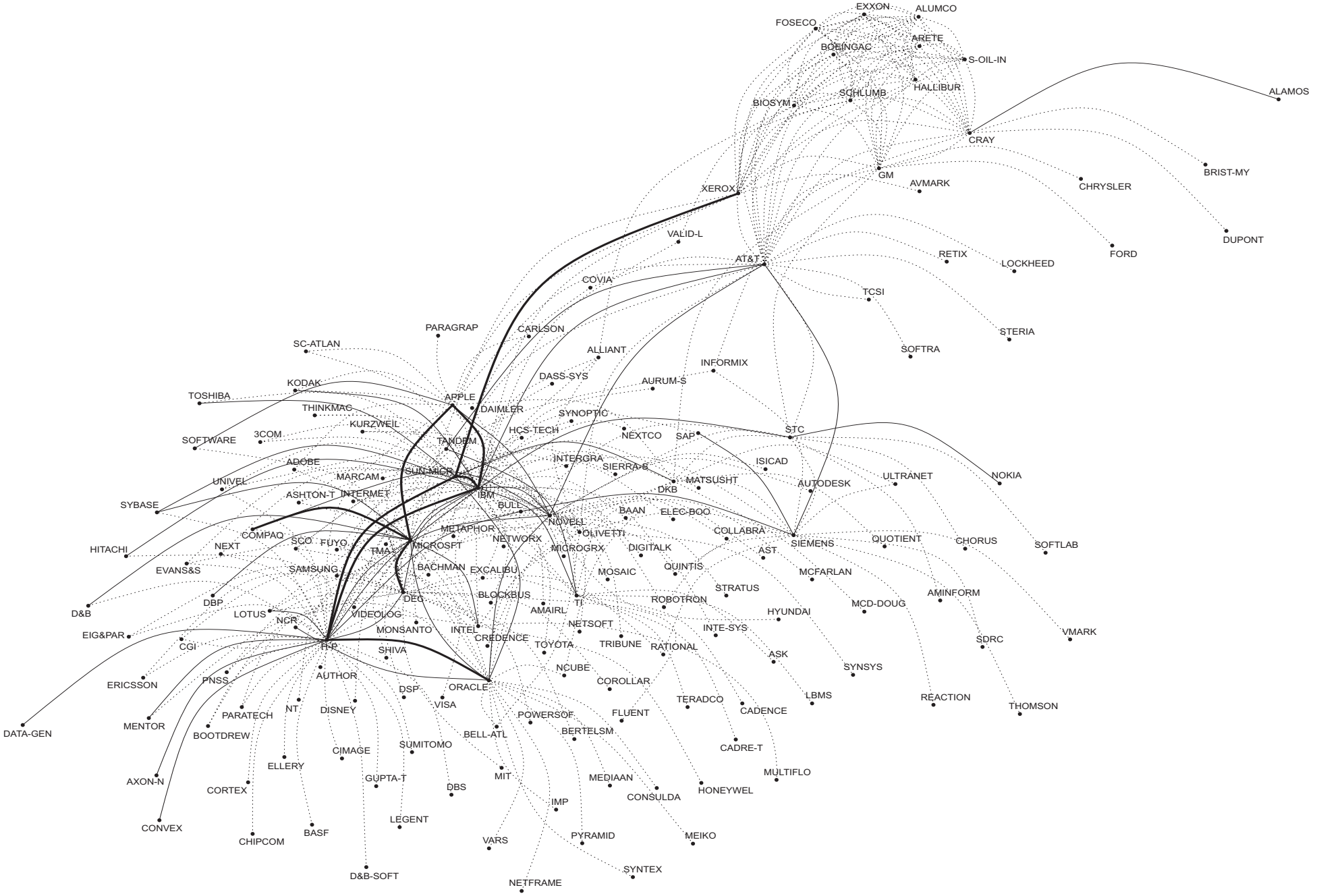


Figure 5. Inter-firm R&D partnerships amongst cooperating companies in software, 1990-94; *source:* MERIT-CATI.

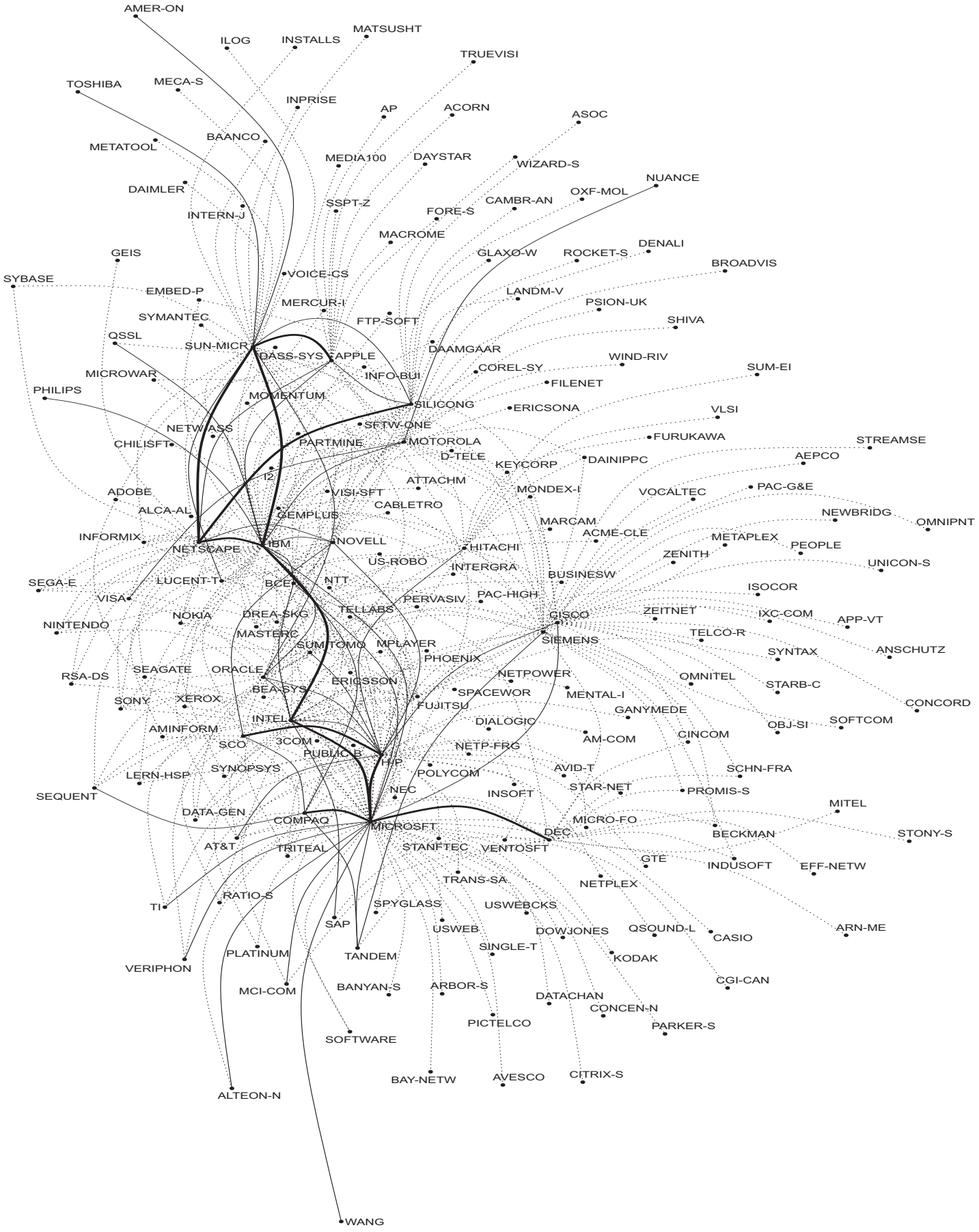


Figure 6. Inter-firm R&D partnerships amongst cooperating companies in software, 1995-99; *Source:* MERIT-CATI.