

December 2007

# Lifting the Hood of the Technological Evolution Process for Web Technologies

Samer Faraj

*University of Maryland RH Smith School of Business*

Adrian Yeow

*University of Maryland RH Smith School of Business*

Follow this and additional works at: <http://aisel.aisnet.org/icis2007>

---

## Recommended Citation

Faraj, Samer and Yeow, Adrian, "Lifting the Hood of the Technological Evolution Process for Web Technologies" (2007). *ICIS 2007 Proceedings*. 140.

<http://aisel.aisnet.org/icis2007/140>

This material is brought to you by the International Conference on Information Systems (ICIS) at AIS Electronic Library (AISeL). It has been accepted for inclusion in ICIS 2007 Proceedings by an authorized administrator of AIS Electronic Library (AISeL). For more information, please contact [elibrary@aisnet.org](mailto:elibrary@aisnet.org).

# LIFTING THE HOOD OF TECHNOLOGICAL EVOLUTION PROCESS FOR WEB TECHNOLOGIES

*ICIS 2007 General Topics*

**Samer Faraj**

R.H. Smith School of Business  
University of Maryland  
College Park, MD U.S.A.  
sfaraj@rhsmith.umd.edu

**Adrian Yeow**

R.H. Smith School of Business  
University of Maryland  
College Park, MD U.S.A.  
yongkwang\_yeow@rhsmith.umd.edu

## **Abstract**

*This article uses an evolutionary networking perspective to develop a Spiral Model of technological evolution for web technologies. This model is grounded in archival data concerning the creation and development of web browser and web search technologies (1994-2005). The Spiral Model posits that the evolutionary process for web technologies goes through four interconnected phases: network formation, network contest, blackboxing and dismantling the blackbox. The model highlights the role of technological frames that guide the inscription of artifacts and the enrollment of key actors and technologies into actor-networks. These actor-networks engage in contests as each seeks to impose its frame on the technology. Actors who are successful in this contest can begin to “blackbox” the web technology according to their technological frame. Yet this blackbox state is reversible, and is subject over time to both endogenous and exogenous triggers that may begin to dismantle these blackboxed technologies. This phase leads to another round of network formation and contestation. The result is an ever-tightening spiral of change in the two technologies.*

**Keywords:** Technological evolution, blackbox, technological frames, inscription, enrollment, Web browser, Search Engine

## **INTRODUCTION**

Starting in the latter half of the twentieth century, information technology (IT), especially the Internet, has fundamentally changed the nature and rate of innovations and new product development. Despite IT's significant presence and its influence on innovation and change, traditional academic research in the field of innovations has typically treated IT as a blackbox. An oft-cited information systems (IS) research commentary by Orlikowski and Iacono (2001) argues eloquently against such a narrow perspective. Organizational theory literature also points to the unique nature of IT-driven innovations and their impact on firms (e.g., Rindova & Kotha 2001). Responding to

this call for a more nuanced understanding of technologies in the field of IT innovations, we argue for a more specific model for understanding IT innovations. This model should build on current theories of innovation and take into account the specific aspects of the IT artifact.

Starting with Nelson and Winter (1977), scholars who study the process of technological developments have come to recognize that technologies do not develop randomly, but follow a recognizable pattern. This pattern, which can be seen in various technologies, closely mimics an evolutionary process (Abernathy & Utterback 1978; Anderson & Tushman 1990; Dosi 1982). Some researchers who have adopted a technological objective viewpoint have focused on how specific characteristics of the technological artifact interact with their selection environments to influence the evolutionary pattern (Gatignon et al. 2002). However, other researchers have proposed that these artifacts are products of a complex interaction among various issues, tradeoffs, and social-economic actors embedded within the process itself (Akrich et al. 2002; Van de Ven et al. 1999). Thus, two main schools of thought have emerged with respect to the process of technological evolution. The first school of thought is grounded in evolutionary economics. This model, which focuses mainly on the co-evolution of technology and the environment, provides insights into the sequence of path-dependent changes following a technological discontinuity (Dosi 1982; Nelson & Winter 1977). Some scholars trace the origins of technological discontinuities to architectural technological innovations that are defined as radical and competence-destroying in nature (Gatignon et al. 2002; Tushman & Anderson 1986). Although such innovations tend to be seen in retrospect as superior from a technological standpoint, this is no guarantee of success (Van de Ven & Garud 1989).

Other scholars have emphasized sociological and cognitive explanations to propose a socio-cognitive model of how technological changes emerge and evolve (Garud & Rappa 1994; Kaplan & Tripsas 2005). The socio-cognitive model emphasizes the reciprocal interactions between cognitive and social processes. A related stream of research in science technology studies also emphasizes the role of cognition in the form of technological frames on the process of technological evolution (Bijker et al. 1987). These technological frames are the main mechanisms in the process of technological change, since this process starts with negotiations among these frames and ends when the negotiations reach closure. Bijker et al. (1987) posit that technological paths are inherently socially constructed and are not simply determined by the characteristics of innovations.

While the socio-cognitive perspective attempts to provide micro-level insights into the sources of innovations, other innovation scholars point out that the main driver behind innovations and technical change has been shifting from individuals and singular firms to “communities” of related firms (Rosenkopf & Tushman 1994; Swanson & Ramiller 1997). The “network” approach to innovations basically suggests that radical technological change is embedded in networks of technological communities, within which structural changes in actors, linkages and power influence the technology base (Rosenkopf & Tushman 1994). This approach explicitly recognizes that as technologies increase in complexity and uncertainty, the result is a greater interdependence in the evolution of their core and subsystems (Rosenkopf & Tushman 1994). This technical interdependence in turn implies an increased interdependence among various actors with specialized functions—individuals, organizations and institutions (Van de Ven & Garud 1989). Networks of technological communities eventually emerge from the interactions among these interdependent actors. Actors may include suppliers, manufacturers, resellers, users, governmental agencies, universities, standard-setting bodies, professional associations and individuals (Rosenkopf & Tushman 1994; Van de Ven 2005).

The literature also suggests that as firms collaborate in these networks and pursue efforts to standardize technology, the networks in return provide the impetus to change and stabilize the resulting innovations (Garud et al. 2002). Like evolutionary models, the network perspective recognizes that network communities evolve along with technologies (Rosenkopf & Tushman 1998). Recent empirical studies have attempted to integrate the social process model with the network perspective (Garud et al. 2002). These studies highlight the technical coordination and collaboration among actors within these networks, as well as the importance of creating and managing social ties among the many diverse, distributed and embedded actors.

IT development in the web environment represents a unique setting for understanding technological evolution. In comparison to other innovations and technologies that have been studied previously (e.g., cochlear implants (Garud & Rappa 1994) and 3M sticky notes (Van de Ven et al. 1999)), IT on the web develops faster (Cusumano & Yoffie 1998) and involves technologies that are relatively more complex given the greater amount of underlying component technology and more potential linkages among these components. Additional defining features of IT systems are that they are extremely open and have wide applications (Agarwal & Sambamurthy 2002). Web technologies in particular tend to be highly malleable and thus may be less limited by history (Sproull & Goodman 1990).

Because of these factors, IT and web technologies are imbued with an especially high degree of uncertainty (Weick 1990). This uncertainty requires organizations and individuals to engage in a significant amount of sensemaking (Bijker et al. 1987). This sensemaking is not only cognitive and symbolic; it is also substantive in terms of the actors' actions toward the technological artifact and other social actors (Latour 1987). Moreover, IT is an open and interconnected technology and its development is largely driven by communities or networks of actors. In view of these key contextual and technological characteristics, in this paper we propose an evolutionary networking perspective that focuses our longitudinal analysis of cognition and actions beyond a single focal actor to include multiple actors. This perspective emphasizes the actions and cognitions of these actors that create the interdependent relationships among key actors, as well as the impact of these emergent social networks on the technological development process.

Using the evolutionary networking perspective we propose a Spiral Model of technological innovation based on a study of two key web technologies: web browsers and web search engines. Despite the prevalence of these two technologies, questions as to how they evolved and why they took their current configuration remain unexplored from the standpoint of technology evolution.

This paper is organized as follows: The next section discusses the qualitative approach and methods used in this study, which are in line with the logic of inductive studies. We then explicate the Spiral Model based on data concerning the development of the two web technologies. Finally, we discuss the implications of our model for refining current perspectives on technological innovations.

## **Data & Methods**

### ***Data Sources***

For this study, we collected from multiple publicly available sources archival information pertaining to the development of web browser and web search technologies. This pair of technologies was selected in part because they are vital components of the Internet infrastructure and have parallel historical profiles. Web browsers are well-known as "gateway" applications (Garud et al. 1998) that end-users use to access the Internet. Search engines are equally integral to the development of the Internet industry, since they are the primary technology for accessing sites and content of interest. Early prototypes of these web technologies appeared circa 1990-91 in technical and academic domains. In 1994 commercial versions of these technologies emerged and were provided "free" to users, leading to multifaceted technology and marketing innovation battles involving several firms.

Following previous researchers, who have used archival data to study transformation in technologies, institutions and organizational strategies (Garud & Rappa 1994; Rao 1994; Rindova & Kotha 2001; Van de Ven & Poole 1990), we conducted an extensive search of archival data covering the development of these two technologies. Specifically, we searched the Lexis-Nexis database of newspapers, trade journals and magazines. We found articles from national newspapers (e.g. The New York Times) and local ones (e.g. the Seattle Times), as well as key trade journals (e.g. PC World). Searching with broad terms like "Web Browser" and "Internet Search engine," we found a total of 2,997 newspaper articles and 2,896 trade journal articles concerning web browsers and 2,704 newspaper articles and 4,638 trade journal articles on web search technology from 1994 to 2005. After reviewing all the articles, we discarded those that were irrelevant<sup>1</sup> or repeated. In cases where articles had been repeated, we chose the version that appeared earliest. The final set of articles included 402 news articles and 648 trade journal articles on browsers and 543 news articles and 438 trade journal articles on web search technology. These articles provided in-depth information on the development of the technologies themselves, interviews with key actors involved in these technologies and coverage of these actors' actions, as well as significant events.

As not all the key players' actions were captured in the media, we also accessed websites of organizations involved in the development of web browser and web search and downloaded relevant press releases, SEC announcements and white papers concerning these technologies as well as websites of standard-setting bodies, government agencies e.g. W3C. Overall we accessed more than 40 websites. We also accessed 14 published studies of key firms and several books that document and discuss the early development of web, web browser and web search technologies (Angel 2002; Battelle 2005; Berners-Lee 1999; Cusumano & Yoffie 1998). Notably, books by Cusumano & Yoffie (1998), Angel (2002) and Battelle (2005) provided insights into the nuances of the development of the web browser and web search technologies, especially the network contest phase.

---

<sup>1</sup> Many articles discussed other activities by the firms involved in these technologies, not the technologies themselves.

The use of multiple sources of data is in accordance with the recommended qualitative research procedure of triangulation (Miles & Huberman 1994; Van de Ven & Poole 1990). Triangulation is especially important in this study of innovation development, as we are attempting to capture various aspects of both technologies (Garud & Rappa 1994) and gain “multiple vantage points” so as to ascertain the accuracy of the events reported on online news sources and the perspectives they put forth (Glaser & Strauss 1967). For example, news articles provided detailed information on organizational actions from a news perspective, but since these were sometimes focused on very specific news items, we supplemented this material with trade journal articles that tend to treat the news in a more in-depth manner. By using multiple sources of information reported by different third-party observers who were there as events were unfolding, we guard against the problems of memory failure, distortion and post-hoc rationalization (Dougherty 1990; Garud & Rappa 1994).

### **Data Analysis**

Following the methods of Garud and Rappa (1994) and Van de Ven and Poole (1990), we first created a chronological list of events of the development of both technologies from 1994 to December 2005, based on all the archival data we had collected. Only incidents that were critical to the development of both technologies were noted in the chronology<sup>2</sup>. The chronology was verified against the alternative sources of data (e.g. external organizations’ websites) to ensure that it was complete and accurate. The resulting base document enabled us to focus on the key actors and artifacts, the moves associated with them, and events affecting the development of the technologies.

After identifying the key actors involved in the process during the period under discussion, we invoked an iterative approach, moving between the data, pertinent literature and emerging theory to uncover key themes of technological evolution in our data (Glaser & Strauss 1967; Miles & Huberman 1994). Our first analysis of the data together with our understanding of the extant literature led us to focus on the micro-processes of technological development—that is, the beliefs of key firms and their actions with respect to enrolling key technologies and allies, as well as their specific contributions toward the development of the technical artifact. Using these key concepts, we created a coding template that we used to systematically code a subset of our data: news articles (Boyatzis 1998). We specifically extracted quotes from interviews with top management executives dealing with their technology frame or their thoughts about their own actions. We used these as representative coding units for the elements we were interested in, since these sampling units tend to be rich and complex (Krippendorff 2004).

Two researchers independently coded the news articles to ground elements of the initial framework. A sample of randomly selected articles (n=100) was used to calculate the reliability of the coding, which was determined by percentage agreement with the presence or absence of each conceptual element in each document (Boyatzis 1998). Cohen’s Kappa is used to complement the percentage agreement, since Kappa statistics deal with both the symmetric issue and the reliability in the data. The results (agreement / Cohen’s Kappa) for each of the three categories were: Technological Frame (95%/0.834); Enrollment (88%/0.76); Inscriptions (90%/0.661). All categories in both tests came close to or exceeded the 70 percent rule of thumb (Boyatzis 1998)

While this first iteration of coding uncovered the key mechanisms through which web technology innovations emerged, we were not able to fully capture how they evolved. Thus, in the next iteration, we focused on the dynamics of the actors and technologies over time. We analyzed and compared the dominant actor-networks for each technology, specifically looking at the ways in which each actor-network’s use of mechanisms and events affected its dominant position.

Finally, as we considered the chronology of key events with respect to these dominant firms, we observed that they eventually faced significant challenges that led to the entry of alternative actors. Thus, we also analyzed the context in which these challenges arose and the character of the new actor-networks. These two iterations allowed us to consider the different phases of the evolutionary process. We then rearranged our coded data elements from the first iteration around these phases and developed tables or displays for each phase (Miles & Huberman 1994). To assist the reader in visualizing the unfolding elements in each phase, we mapped the evolution of these relationships over time onto two network diagrams that display and explicate the overall pattern (Langley 1999; Miles & Huberman 1994). See Figures A1 and A2 in Appendix A.

---

<sup>2</sup> Due to space constraints detailed chronology was removed from the paper but is available from authors upon request.

## Spiral Model of Technological Evolution

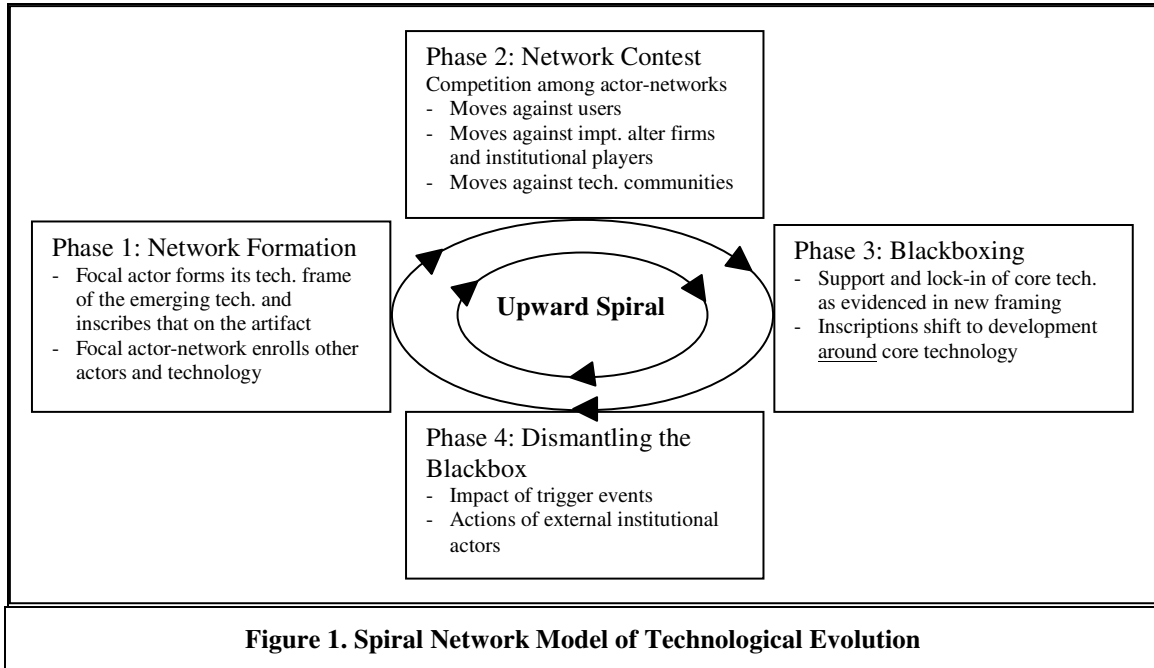


Figure 1 summarizes the model that resulted from our analysis of the evolution of the two web technologies from their invention until the end of 2005. The model focuses on the phases of the evolutionary process and explicates the actions of the key players and events during each phase.<sup>3</sup>

The first phase of the process model is “network formation,” which takes place between the various actor-networks over the technological frames of the emerging web technology. In other words, network formation refers to the activities of early key actors as they attempt to build a coalition of allies to support their technological frame of the emerging web technologies—simultaneously creating the artifact and inscribing their technological frame into it. The central notion in this phase is technological frames. This term is rooted in the concept of frames, which Goffman (1974) defined as “schemata of interpretation to locate, perceive, identify and label” life experiences (p. 21). In short, frames are a way for individuals and collectives to organize experience and guide action (Benford & Snow 2000). Bijker et al. (1995; 1987) define technological frames as frames that serve this interpretive function at a collective level with respect to a new technology. Bijker (1987, 1995) suggested that technological frames consist of elements that influence interactions among actors of a social group, leading to the attribution of meaning to novel technology. Such elements include each social group’s assumptions and expectations about the technology, e.g. its purpose, role and goals; key problems to be solved by the technology; and the evaluation criteria to be used (Bijker 1995). Orlikowski and Gash (1994) proposed a definition similar to Bijker’s in their study of how different groups make sense of new technologies within an organization.

The other central concept is the idea of inscription. In this context, the term is derived from actor-network theory (Callon 1986; Latour 1987) and refers to the process of creating technical artifacts to ensure the protection of an actor’s interests (Garud & Kumaraswamy 1994; Latour 1999). This is achieved when the technology is shaped in such a way as to lead and control users and other designers (Faraj et al. 2004; Hanseth & Monteiro 1997). This is a key process by which actors imprint elements of their technological frame onto artifacts.

The second phase of network contestation represents the crux of the evolutionary process, as it is during this phase that the alternative technological frames embodied in the various actor-networks and artifacts compete for dominance. The frame that emerges the winner in this contest will guide the subsequent development process. Actor-networks are heterogeneous groupings of actors, technologies and resources that form in the earlier phases.

<sup>3</sup> Tables summarizing evidence (quotes from key players and articles) for each phase of the model were removed due to space constraints but are available from the authors.

The defining characteristic of an actor is that it is able to “make other elements dependent upon itself and enroll their will into the language of its own.” Actors’ will or agency is defined by their beliefs and cognitions regarding the technology (Law 1992; Van House 2003). During the competition phase, each actor-network engages in targeted enrollment of important actors and technologies. Enrollment is defined as the ways in which actors seek to actively interest others in supporting the construction of the artifact according to their preferred technological frame. The focal actors’ network seeks by means both direct and indirect to induce other actors and technologies to join it (Latour 1999). The result is the formation of a network where the different actors’ interests are aligned.

The third phase of “blackboxing” occurs when an actor-network manages to overcome competing technological frames regarding the technological artifact and make it part of the overarching architecture of its now-dominant technological frame. Blackbox is therefore defined as “the extent to which it is impossible to go back to a point where that [technological frame] was only one amongst others and the extent to which it shapes and determines subsequent enrollment” (Callon 1986; Latour 1999), and blackboxing refers to the process by which this status is achieved for the dominant technological frame and artifact. In other words, the dominant actor-network has achieved a degree of irreversibility in that the interpretive flexibility of the technical artifact is greatly reduced, if not totally eliminated. The technological artifact is intrinsically tied to the dominant technological frame. Practically speaking, a “blackboxed” technology is one in which the dominant artifact has reached a point of taken-for-grantedness (Akrich & Latour 1992; Tuomi 2000); at this point, others can unproblematically incorporate the artifact into other technological developments.

Yet this blackbox state is inherently precarious in that there are always pressures on it and opportunities for it to break down (Callon & Latour 1981). Thus, the fourth phase deals with the “dismantling of the blackbox”. This phase is characterized by various triggers that are either part of the endogenous development or occur as exogenous events (Hughes 1989). With the appearance of these trigger events and the emergence of alternative technological frames that take advantage of them, another round of network formation and contestation begins, although at a higher level than the first round. This new phase is similar to an upward spiral since it is partly derived from the previous round but has a different set of emphases and actors. This accords with the idea that innovative activities are basically a “circulation space of statements and other intermediaries” (Law 1986).

## Phase 1: Network Formation

In tracing the histories of the two web technologies, we found that the evolutionary process begins with the efforts of the focal actor (a firm or individual) to form a network of heterogeneous actors and artifacts to mold the emerging web technology according to the preferred technological frame. We found evidence in media reports and interviews that the technological frames of the focal actors influenced how they created and designed web innovations. More importantly, these frames guided how they built relationships with other actors and what other artifacts and technologies they incorporated into their creations (Kaplan & Tripsas 2005).

The evolution of commercial web browsers began when Marc Andreessen and Jim Clark formed Netscape Corporation<sup>4</sup>. These two men said in interviews that Netscape’s technological frame envisioned its web browser becoming “a universal interface that would tie the networks of the future together.” Netscape firmly believed that web browser technology represented a significant broad-based shift in interface technology, as computing moved from desktops to networks. Thus, the company’s web browser had to be cross-platform, designed for network services, rather than functioning just for the desktop on one type of operating system (OS).

These salient elements of Netscape’s technological frame were evident in its web browser artifact, as seen from the company’s inscriptions: Netscape’s core module – Netscape Portable Runtime that allowed it to abstract away from core OS functions and support any type of OS. The company also chose to incorporate Sun Microsystems’ Java programming language to make its web browser capable of running various applications stored on Internet servers, with the result that web-based applications can be platform-agnostic (Cusumano & Yoffie 1998).

To promote the technological frame embodied in its web browser artifact, Netscape began forming an actor-network. This included co-opting significant industry players like Sun Microsystems. More importantly, Netscape reached out to early adopters by providing its web browser free to consumers on the Internet. To build its distribution network,

---

<sup>4</sup> Other web browser companies like Spry and Spyglass appeared around this time, but they were all licensees of NCSA’s Mosaic browser code and did not contribute substantially to the development of the web browser once Netscape appeared on the scene.

the company made deals with computer OEM makers and prominent ISPs. This allowed Netscape to quickly emerge as a key player in determining the development of the web browser.

In the field of web search, two groups with different approaches emerged around the same time. The first group, as exemplified by Lycos, grew from information retrieval techniques developed in the library sciences (Schatz 1997). Hence Lycos' technological frame is grounded in the library science "paradigm". Specifically, Lycos adapted for the Internet technologies used to search bibliographic and full-text databases, building a software-enabled search engine that allowed Internet users to look up websites using keyword queries. These keyword queries are matched against an index created by software agents ("crawlers"). Lycos' ties to universities and the established online database industry enabled it to successfully gain funding from venture capital firms, which it used to launch its web search service on the mass market (Battelle 2005; Rindova & Kotha 2001).

The second group, which was mainly dominated by Yahoo, included websites that provided a directory that classified web addresses into different categories. This approach was based on the concept of a physical library card catalog, in which searchers use broad subject categories to locate a particular selection of links, then browse through those links to find the desired address link (Angel 2002; Schatz 1997). The technological frame of directories can be summed up in two words: "navigation guide" (Tim Koogle). This technological frame differs from the first group in that it puts specific emphasis on being a service to its users (David Filo and Jerry Yang). Thus, Yahoo's hierarchical subject directories are usually compiled and indexed by human beings. This feature, together with Yahoo's intuitive and easy-to-use interface, allowed it to gain the support of many early Internet users (Sacharow 1997).

Even as these focal actors' networks begin to take shape and achieved some success in inscribing their technological frames into the web browser and web search technologies, contests over these technological frames' claims to the emergent technologies quickly followed. This contestation forms the core component in the evolution of these technologies, since it came to characterize the interaction among the different actors, networks and technological frames, and determined how the contest was resolved interactively. In the next section, we describe how this phase played out with regard to the web browser and web search technologies.

## **Phase 2: Network Contest**

The contest among competing networks of focal actors essentially revolved around the framing of the new web technologies, as can be seen in the many contemporaneous media and trade journal articles covering these new web technologies. For example, one Netscape executive summed up the web browser contest as basically a "battle of what is the platform DNA" (Tom Paquin in Cusumano & Yoffie 1998).

This contest was embodied in the enrollment and counter-enrollment undertaken by the focal actor-networks. Based on our analysis, we observed that enrollment was aimed at specific targets (users in the market realm, developers and early institutional players in the technical realm, and business partners in the business realm) using different economic, technical and political logics (Latour 1999).

Enrollment initially involved strategic moves by focal actor-networks to induce potential users to adopt their technologies. The actor-networks sought to subtly mobilize these users to evaluate the available technologies according to their preferred technological frames. Appeals to users whose needs seemed most in harmony with the focal actor-network's technological frame seem to have been the most successful. For example, Netscape's browser appealed directly to consumers who used different OSs, particularly corporate information systems managers who usually managed a diverse set of servers using different OSs. In Yahoo's case, the directory model had an intuitive look that most users found easy to relate to and use (Moody 1994).

In the next stage, the focal actor-networks sought to enroll the business community, with the aim of ensuring a network conduit to support enrollment momentum among users (Van de Ven 2005; von Burg 2001). These approaches toward the focal firm's important business partners are also vital in ensuring the performance of the focal actor-network and the artifact. In the case of web browser technology, computer OEM makers and Internet service providers (ISPs) were the partners; they acted as different channels for reaching consumers, corporate users, independent software vendors (ISV) and the developer community, which assisted by providing crucial technical feedback and sometimes contributing to the browsers' technical refinement. These enrollments were possible because of artifacts that Netscape created: the company created plug-in architecture and opened its APIs to ISVs so that they could write applications for its web browser. Microsoft countered with a robust and aggressive program to lure Netscape's partners away from its network. Microsoft also made a significant investment rewriting its Internet browser as a fully componentized application that was embedded in its (then) new OS, Windows 98. Not only did



this provide superior performance in the Windows environment as compared to Netscape's Communicator, it also allowed private labeling of the web browser – AOL was won over through this tactic (Cusumano & Yoffie 1998).

In the case of web search technology, there was a high degree of uncertainty over who the focal actor-networks' key partners were. The early competition drove web search companies to enroll important user groups. For example, Yahoo had close ties with the community of web surfers, which enabled it to provide more relevant results (Rindova & Kotha 2001). As the business evolved, Yahoo capitalized on this "grass roots" connection by re-organizing its web search to appeal not only to individual users but also to corporate advertisers. It did this, for example, by streamlining its categories and building theme-based guides and localized directories with personalization technologies. This also provided Yahoo with a strong platform for enrolling content providers and the media. In contrast, the keyword-driven search companies had mainly targeted "expert" and power-search users. They took some time to change course; Excite was the quickest at imitating and counter-translating Yahoo's moves (Rindova & Kotha 2001). Newer keyword-search players like AltaVista made significant improvements to the underlying technology, but did not improve their actor-networks enough to compete with Yahoo's model. Each of them in turn was strategically co-opted by Yahoo as part of its own network (Angel 2002).

Finally, there were moves to enroll key actors in the technical communities. The goal of these moves was to inscribe key elements of the focal actor-network's technological frame in the collective technical frame. This indirectly solidified the focal actor-network's ties with its users and key business partners, as these positively influenced users' and partners' perception of the focal actor-network's technological expertise. On a subtler level, the more successful the focal actor-networks are in translating the technical communities, the more likely it is that their web technologies will be evaluated favorably, since they are able to "skew" the playing field to the advantage of their own technologies. For example, Netscape was actively engaged with the open standards community, and this involvement gain it support for many of its own technologies, e.g. LDAP and SSL. In the case of web search technology, Yahoo chose to hire ontological specialists to ensure that the submitted weblinks were "correctly" classified within its categories (Angel 2002).

As discussed above, we found that individually the three sets of enrollment and counter-enrollment moves served as the main mechanisms by which the focal actor-networks competed. However, the successful actor-networks did not just focus on one set of moves; instead, it managed them in a complementary fashion (Milgrom & Roberts 1995). Microsoft's ability to counter-enroll users was not just an economic (free product) and network effect; it was also determined by its robust moves to lure away Netscape's key business partners and its moves to enroll members of the technical community. Yahoo's ability to capitalize on its popularity due to the ease-of-use of its interface was in part due to its continued enrollment of key business partners and its strategic moves to co-opt potentially powerful start-up web search engines. Their success is evident in their dominance of their respective markets.

Interestingly, though, the emergence of this dominant frame does not necessarily entail the demise of alternative frames. In the case of web search technology, the dominant frame incorporates elements of both directory and keyword web searches, so it maps closely to the constructivist notion of a negotiated frame. In the case of web browser technology, Microsoft's dominant frame incorporates some superficial elements of Netscape's frame, e.g. the incorporation of Javascript and some cross-platform IE. Yet within a few years, Microsoft fundamentally rejected the network-centric frame and forged ahead with its own OS-centric web browser. Despite that, the network-centric frame still exists, albeit as a peripheral actor in the form of Mozilla.org. The process that developed next is described in the next section.

### **Phase 3: Blackboxing**

After the emergence of a dominant actor-network, we observed that there was a gradual but significant change in both the framing of the actor-networks with regard to the technological artifacts and their inscriptions in the technological artifacts. These changes were also reflected in the altered pattern of enrollment moves the dominant actor-networks made to support this shift.

Specifically, the dominant actor-networks began framing their actions away from the web technologies themselves. This is evident in both the interview data and media reports. For example, Microsoft shifted the focus of its web browser, changing it into an Internet command post of which IE is just one component (Markoff 2001). Netscape shifted their focus from their browser to its web and corporate services (Corcoran 1998). In web search technologies, the shift has been even more significant, with Jerry Yang proclaiming that Yahoo, the company he co-founded, is no longer a search company but a portal and a media network (Krantz 1998).

The focal actor-networks also began a series of subtle but deliberate inscriptions that extended these technologies in such a way as to give them a sense of inevitability. In the field of browser technology, Microsoft began building “mega-browsers” that incorporated many additional functionalities such as built-in multimedia applications, communication applications, content and online services (Bray 1998; Katz 2000; Schwartz 1999). The company also ostensibly stopped developing and supporting cross-platform web browsers. By associating IE with more technologies and making it look extensible, Microsoft actually made the underlying browser technology more solid and opaque, and therefore less open to interpretive flexibility. Similarly for web search, one article noted that “[t]he folks at Yahoo, Excite and Lycos don't want you to notice the mechanics of their Web-search software. They want to be user-friendly media companies. ‘Technology’ is a word to be avoided.” (Stone 1998). Like Microsoft, Yahoo and the other portal companies (as they came to be called) began embedding more interactive services in their websites, thereby relegating the web search function to a secondary status (see Figure A2).

In addition, focal actor-networks continued to enroll other key actors to sustain this blackboxing process. The pattern, however, reflected the new focus in that the key actors tended to sustain firms offering the new add-on technologies, such as content providers, as distinguished from the previous set of actors, who had a direct connection with the underlying web technology. Apart from the change in the target actors, the need for new enrollment moves shows that the “blackboxed” state is inherently precarious and at best tenuous (Callon 1986; Latour 1987). Unlike the technologically deterministic notion of innovation trajectory, a dominant technological frame requires persistent actions to sustain its dominance. To be successful in keeping the technological artifact “blackboxed”, actor-networks have to be on top of emergent technological issues that can potentially challenge their technology and technological frame. If the focal actor-networks remain ignorant of these potential challenges, they set the stage for the breakdown of the blackboxed technology, as we observed in the next phase of evolution.

#### **Phase 4: Dismantling the Blackbox**

“Dismantling of the blackbox” describes a situation where significant exogenous events and endogenous developments of the web technologies and the focal actor-networks reopened the debate over the validity of the dominant technological frames. Together or separately, these triggers became the underlying motivations for external actors to react against the dominant technological frame (Griffith 1999; Hughes 1989).

From the media reports, it seems that the ongoing efforts to blackbox the core web technologies may have ironically created the conditions that led to these triggers. In both cases, the shift in focus from developing the core technologies to working on other related technologies led inevitably to degradation in the core web technologies’ performance. For example, the relegation of web search technology to a secondary role within a web portal resulted in the “dumbing down of web search” (Hane 1999). In the field of web browser technology, Microsoft made only small incremental improvements to its Internet Explorer after version 5.5. As a result, Microsoft began to lag behind in terms of its support for open standards and other key-browser related developments; for example, IE 6.0 provided little support for W3C’s standards (Farrell 2000).

The decline in technological innovations, together with significant changes in the external environment, gave rise to a set of critical exogenous trigger events. In web search technology, the rapidly expanding Internet universe and the weaknesses of most web searches (e.g. inadequate indexes, low refresh rates and large quantities of irrelevant results or “dead links”) led to the phenomenon of the “invisible web” (Sherman 1999; Sherman & Price 2001). The web portals’ high dependence on advertising and commodity portal content and services further alienated Internet users (Cheng 1999). Web browsers faced a similar situation where their many new add-on technologies, e.g. media players, led to the development of “bloatware” (Farrell 2000).

The underlying web browser and web search technologies were also subject to exploitation by “malignant” actors. For example, hackers and other malware developers quickly exploited the tight integration of the web browser with the OS to introduce software viruses into unsuspecting web browser users’ machines (Festa 2004a). Spammers exploited the method by which search engines collected and ranked search results to artificially boost their websites’ relevance ranking. All these generated negative publicity and the apparent lack of response from the focal actor-networks exacerbated the situation. It was an opportune point to reconsider the dominant actor-networks and their technological frames (Elsbach 1994).

More importantly, some of the earlier enrollment moves used by focal actor-networks created significant triggers for external actors to react against them. Web search companies had attempted to enroll key advertising partners by adopting practices like “paid inclusion services,” where companies pay web search companies to guarantee that their

websites appear in search results, and “paid placement,” where companies’ website are guaranteed a specific spot in search results. External actors like consumer associations charged that these practices tainted the “objectivity” of search results and therefore the functionality of web search technology (Salkever & Prasso 2001).

Microsoft’s robust and aggressive counter-enrollment of Netscape’s partners created concern among institutional actors such as the U.S. Department of Justice (DOJ), leading to a series of antitrust suits. In late 1998, DOJ and the attorneys-general of 19 U.S. states filed an antitrust suit against Microsoft. The European Union (EU) followed suit in 2000 (Watson & Harrington 2000). At the center of these trials was Microsoft’s dominant technological frame, which pushed for tight integration between its web browser and its Windows OS, and the counter-enrollment it used to propagate this frame. In 2000, a federal court found Microsoft guilty of violating the Sherman Antitrust Act, while the EU fined Microsoft in 2004 (Greene et al. 2004). Although Microsoft managed to prevent the breakup of its various divisions, its technological frame of tight OS integration was brought into question.

Thus, a number of events laid the groundwork for alternative technological frames to surface. These alternatives had been in the background, but they were now able to take advantage of the changed situation to start another cycle of evolution. However, instead of starting over from scratch, this new cycle in the evolution of web technologies represents a new round of innovation that builds on elements that were already in place. We represent this fact with an upward spiral model that depicts this next phase as existing on a higher plane than the previous cycle (see Figure 2). We describe the formation and contestation of this new cycle in the following section.

## **Next Level of Network Formation and Contest Phases**

We have observed that in the next round of the evolutionary process, the alternative technological frames that arise to challenge the dominant technological frames build on some key lessons learned from the earlier phases. In this new round, the alternative actor-networks adapt their frames to incorporate elements that can help them leverage the trigger events that occurred in the dismantling phase. For example, Mozilla’s technological frame is inherently similar to Netscape’s network-centric browser frame, albeit with a strong emphasis on user choice. Further, Mozilla learned from Netscape’s competitive experience and the trigger events, so its technological frame emphasized specific aspects of its web browser, which gave it an edge over Microsoft. (Festa 2004b). In the field of web search technology, Google’s technological frame eschews portal-like features, aiming only to provide fast and relevant search results through a new algorithm and a robust backend infrastructure (Lundquist 1999). It focused on improving that underlying search technology and applying it to a wider range of online content and activities. These technological frames, like the earlier phase, are evident in the inscriptions on the web artifacts.

As in the previous network contest round, the focal actor-networks focused on users, especially those whose needs had not been met by the dominant actor-network (Festa 2004b; Welles 2002). Although statistics vary by market segment and geographical location, Mozilla Firefox is estimated to have around 12 percent overall market share. Mozilla has also enjoyed some success in academic institutions and government agencies due to its high-security features. In the field of web search technology, Google was equally aggressive in its enrollment of users, using a similar grassroots-based word-of-mouth movement. Google’s market share very quickly eclipsed Yahoo’s, and the company has achieved a dominant position in the web search industry.

Both of the dominant actor-networks engaged in a series of attempts to inscribe the features offered by the new competing actor-networks into their own artifacts. Microsoft, for example, announced the development of a standalone browser that would be available for Windows XP SP2 and Windows Server 2003. This new browser, named IE 7.0, was to include popular Firefox features (e.g. tabbing and security features). Additionally, Microsoft stepped up its efforts to fix known bugs and provide better support for standards (Rapoza 2005). Yahoo in turn also moved to match Google’s technology: it acquired Google’s main text-indexing web search competitors to create its own search index and algorithm. It also acquired Overture’s search marketing capabilities in order to monetize its keyword search and provide an alternative to Google’s highly successful text advertising network (Krol 2005).

In a strategic move to attract key business partners, Mozilla created a for-profit organization (Mozilla Corporation) to manage its relationships with key corporate, governmental and educational institutions (Markoff 2005). Of special interest is the relationship between Mozilla and Google—the latter is Mozilla’s default startup page. Google shares part of the search ad revenue from this arrangement with Mozilla (Athavaley 2005). Separately, Google has managed to win major advertising accounts, most notably the AOL account. Using innovative technologies, Google has also managed to build one of the most extensive small advertiser based networks on the Internet. As Google

continue to extend its search utility to take in additional types of online content, the company has begun to forge new relationships with entities like libraries, publishers and e-commerce sites (Battelle 2005).

Mozilla and Google both have strong advantages in their respective technical communities. Mozilla's advantage stems from the fact that it is organized around the open-source model. Thus, its development is inherently owned and driven by the technical community, which makes it especially effective in its efforts to deal with bugs and security issues<sup>5</sup> as well as being open standards compliant (Network News 2002). Google was a product of academic research, and its management has maintained this connection with the company's roots in the academic and technical communities. In addition, Google has proactively cultivated these ties by organizing programming competitions. Additionally, it is leveraging its strong internal R&D culture in maintaining these ties (Pontin 2002).

The dominant actor-networks have also made new moves in response to Mozilla and Google. Microsoft is rebuilding its ties with the technical community with regard to its web browser by creating an online community for developers. For example, it made the IE 7.0 development process transparent through blog and chat sessions between its team and technically inclined users and developers (Festa 2005). This online forum mimics the feel of Mozilla's open-source community. Yahoo, which was organized as a media network, has a wider gap to close in this area. After acquiring technical search assets, Yahoo embarked on some moves to build its ties with the technical community, most notably by setting up a search lab at the University of California, Berkeley (Kopytoff 2005).

In summary, our model proposes that the formation of actor-networks, the contest among competing actor-networks and the outcome of this contest set the stage for the evolution of Internet technologies. More importantly, even as technologies achieve blackbox status, there is always the possibility that subsequent events and competing actor-networks will reopen the blackboxed technology, leading to another round of network contestation, which results in an ever-tightening spiral of change.

## Discussion and Conclusions

In this study we identified four distinct but connected phases in the evolution of web technologies over the course of 12 years (1994-2005). In both technologies, the early phase is marked by the formation of networks around emergent technological frames with regards to the novel technologies. Each network was simultaneously creating the artifact inscribed with their technological frame. In a second phase, the various networks actively enroll allies and enter into a contest with each other. As a dominant actor-network surfaces from the contest phase, there is a gradual and significant shift in both framing and enrolment strategies that mirror the dominant actor-network's attempt to "blackbox" the key artifact. This is the third distinct phase of the model. However, much of the decisions and inscriptions that allowed the dominant design to emerge can be detrimental over time as external events trigger unforeseen change and new actors emerge to offer increasing challenges to the existing technological frame. We refer to this phase as "dismantling the blackbox". When the dominant frame is sufficiently challenged, we find the start of another cycle of similar process – network formation and network contestation where new actors engage existing ones in the creation of new sets of artifacts and alliances. Drawing on these findings we developed by induction a model of technological evolution grounded on the notions of technological frames, actor-networks, enrollment, inscription and blackboxing. Unlike deductive research, the key contribution of this inductive model is to generate new insights into the process of emergent IT and web innovations. The implications of these insights allow us to suggest various refinements to both cognitive and network perspectives of the process of technological change.

### *Refining the cognitive perspective*

Our findings build on recent efforts to account for the role of cognition in existing evolutionary models of technological change (e.g., Garud et al. 2002). As noted above, the socio-cognitive model emphasizes the reciprocal interactions between cognitive and social processes, with technological frames serving as the main mechanism. The notion of technological frames in our model shows the important role that cognition of technology plays in the technological evolution process. Specifically, our model provides a thick description of the role of the key actors' technological frames in the technological evolution process. We suggest that in the network formation phase, the

---

<sup>5</sup> Mozilla has a lead over Microsoft in terms of response time and the proportion of high-severity vulnerabilities (Symantec 2005).

technological frames of the focal actors influence and guide the creation and development of the artifacts and the initial network formation.

While our model affirms the cognitive perspective to the evolutionary process of technological change, we also enrich this emerging stream of research. First, we show that there is value in combining the analysis of cognition and behavior of actors involved in the technological change as they complement each other to provide a holistic picture of technological evolution. We show, on one hand, how key actions (e.g. enrollment of other strategic actors and inscriptions) directly flow from the technological frames and in turn constrain or enable these frames. On the other hand, the series of enrollment that occur in the network contest is crucial in understanding how one technological frame can overcome other technological frames. So, even though emerging technology may be abstract and in a sense “resides in the minds of individual” (Garud & Rappa 1994), how one technical form emerges and comes to dominate the others can be best understood by studying both cognitive and behavioral traces.

Second, our results point to a more flexible and realistic outcome of the contest between the various technological frames. Cognitive and sociological perspectives on technological change tend to predict the emergence of a negotiated collective frame that maps to the dominant design. But in our data, we found that the dominant technological frame that emerges may or may not be negotiated. While web search technology reached a compromise in which the search engines that emerged drew on both the directory model and the keyword model, web browser technology came to be based mainly on Microsoft’s technological frame of OS-centric web browser.

“Winners” of the network contest attempt to solidify their position by imbuing their technological frame and artifact with a sense of inevitability, or “taken-for-granted-ness” (Callon & Latour 1981). This is achieved by shifting the focal artifact to the periphery while investing in development of peripheral artifacts and technologies that build on the focal artifact. It also involves a subtle shift in the technological framing to match the shift in technical development. The goal is to simply “blackbox” both the technological artifact and the technological frame. In some ways this is the same thing as the emergence of a dominant design, in that there is one main technological frame. However, in such a situation it is generally recognized that the blackboxing of the dominant design is not unproblematic, so the focal actors must continually act to sustain the blackboxed artifact and frame.

Previous research had assumed a relatively simple reciprocal relationship between technology frames and artifact in which the technological frame shapes technical artifacts while the artifacts both enable and constrain the technological frame. Our model shows that the actor-network’s focal actor, i.e. the key innovator/innovating firm’s technological frame, tends to be the one that shapes the artifacts in order to both enable and constrain the other actors’ technological frames. In certain cases, technological inscriptions made early on by the focal actor may evolve to constrain and even challenge the focal actor’s technological frame. For example, this occurred when Netscape’s inscription of Java technology into its web browser later became a severe challenge to its own frame when Java became too problematic to implement. This may also occur when inscriptions in technical artifacts get out of sync with the external environment—for example, when the tight coupling between the web browser and the OS became a feature that hackers could exploit. In this case, the “slippage” opens a window for alternative technological frames to (re)emerge, thereby leading to changes in the focal actor’s technological frame. All together, these findings show that more research is needed into the reciprocal interactions between artifacts and technological frames.

### ***Refining the network perspective***

This research contributes to recent work on the effect of the social aspects of the network perspective on technological evolution. Although the network perspective draws from social network theory and the science technology studies, the social processes that under-gird the formation and maintenance of these technical networks are assumed and have not been studied. This study adds to the small number of qualitative studies (Garud et al. 2002; von Burg 2001) suggesting that the creation and maintenance of network ties is complex, and that these ties are dynamic, with significant implications for the evolution of the technology. While the network perspective implicitly assumes that social effects become muted once a technological frame and technological artifact achieve dominance, this study shows that the opposite is true, as the focal actors of dominant actor-networks have to continually balance cooperation and competition among the network members (Faraj et al. 2004). Practically speaking, the broader implication of this finding is that successful focal actors need political savvy to understand and mobilize other actors that are perceived to be important to the development of their technological frame and artifacts (Van de Ven 2005). This quality is important during the early phase of technological development, and may be even more crucial in the later phases.

This research also contributes to the network perspective by providing an in-depth description of the process by which the networks emerge and change over time. Since network perspective research tends to study the innovation process using social network techniques, it usually does not provide an account of how firms attain a central position in these networks. This study uses an actor-network approach coupled with the in-depth archival method to trace this specific process from the inception of the technology, which proves the importance of the concept of enrollment to explain how these networks are formed and compete against one another. This ground-up approach is also important to the study of emergent technical innovations, as the scope of the technologies and the boundaries of the networks are not usually known a priori. By following the actions of key actor-networks, we avoid adopting specific a priori community definitions and applying them to data collection and analysis, a mistake which may lead researchers to overlook the impact of important actors and technologies on the evolutionary process.

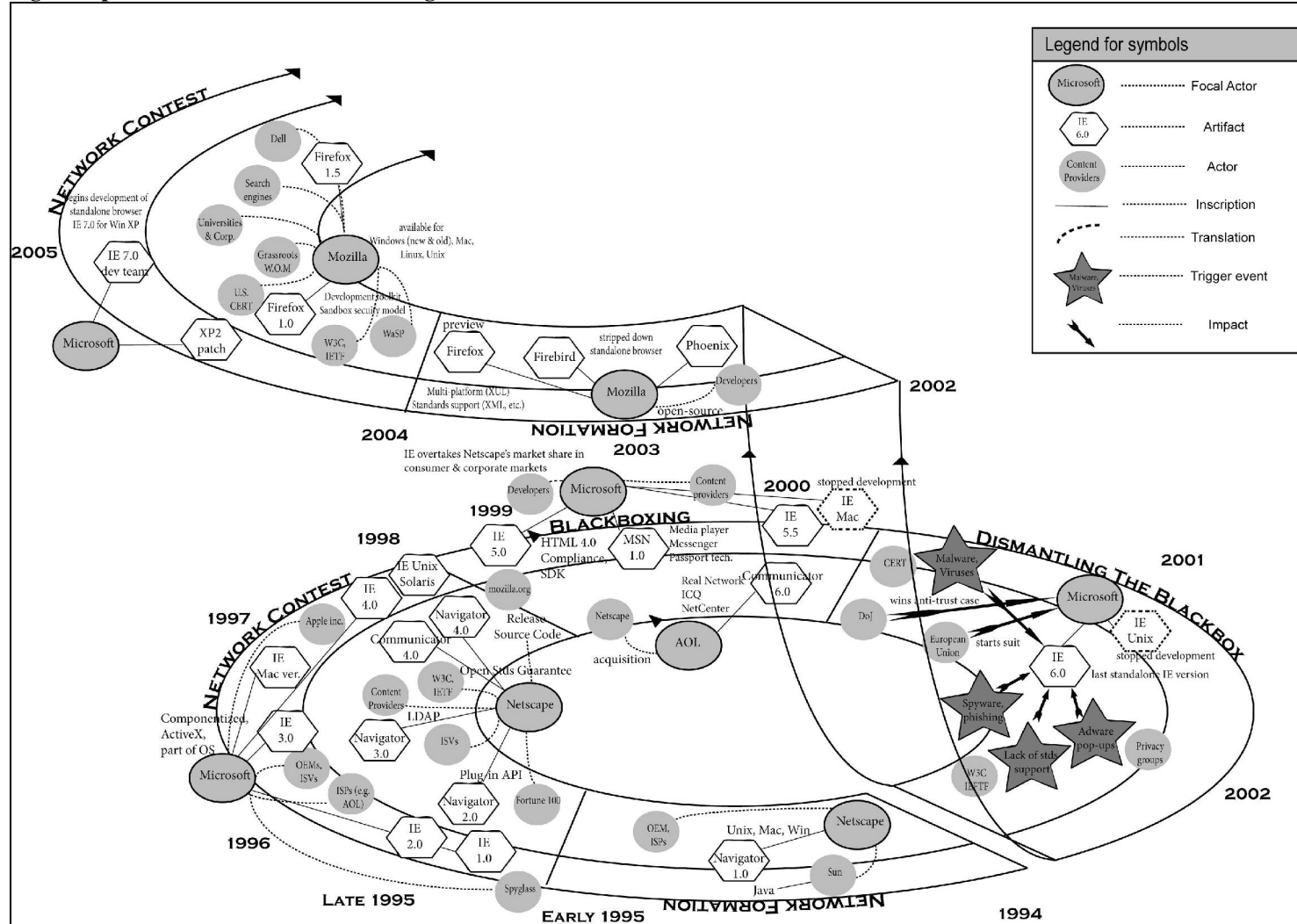
This study's analysis of the blackbox phase shows the importance of network embeddedness in starting a new round of technological change. This study further indicates that one important component for an effective challenge to the dominant technological frame is the ability of the challengers to leverage network embeddedness to exploit triggers. Of special note is the growing importance of user communities and consumer groups as allies of and potential actors within an innovator's network. Contrary to what is stated in most adoption theories, users no longer passively use technology but are actively adapting technology to their use (Akrich et al. 2002; Orlikowski 2000). The latest trend of close collaboration between focal actor-networks (e.g. Google and Firefox) and their user constituencies in the form of betas and "labs" is evidence of this. However, more research on user roles in the technological evolutionary process is required to fully understand the extent of their impact.

Since this study is an early foray in this area and is based on two specific web technologies, we caution against generalizing its results to other contexts and technologies. Another limitation of this study is the use of archival data, which might lead to internal validity threats, in that it requires the researchers to impute features to the technological frames based on what has been recorded instead of being able to directly infer these features from the actors' actions. We have mitigated this potential failing by rigorous coding of the data and triangulation of the records based on various sources.

In conclusion, researchers have called for more research on how IT artifacts are designed and constructed (Orlikowski & Iacono 2001) and as a way to better understand the technological evolution process itself. In response to such calls, we have developed the Spiral Model, which is specific to the Internet, a setting with a high degree of uncertainty, where things are highly dynamic and fluid (Rindova & Kotha 2001). The Spiral Model posits that the dynamic and recursive technological evolution process goes through four interconnected phases: network formation, network contest, blackboxing and dismantling the blackbox. Adopting an evolutionary networking perspective the model provides a rich set of conceptual tools to understand the evolving process of IT innovations. Specifically, the model highlights the role of technological frames in guiding the inscriptions of artifacts and the enrollment of key actors and technologies into actor-networks (Latour 1999). It also shows the complex reciprocal relationship between the technological artifact and various technological frames within the actor-network over time. Finally, the evolutionary networking perspective weaves together the cognitive and technological elements with the network to create a holistic view of the evolution process. We argue that this holistic view, though complex, provides a lens that both researchers and practitioners can apply to further understand the myriad technical changes that surround us.

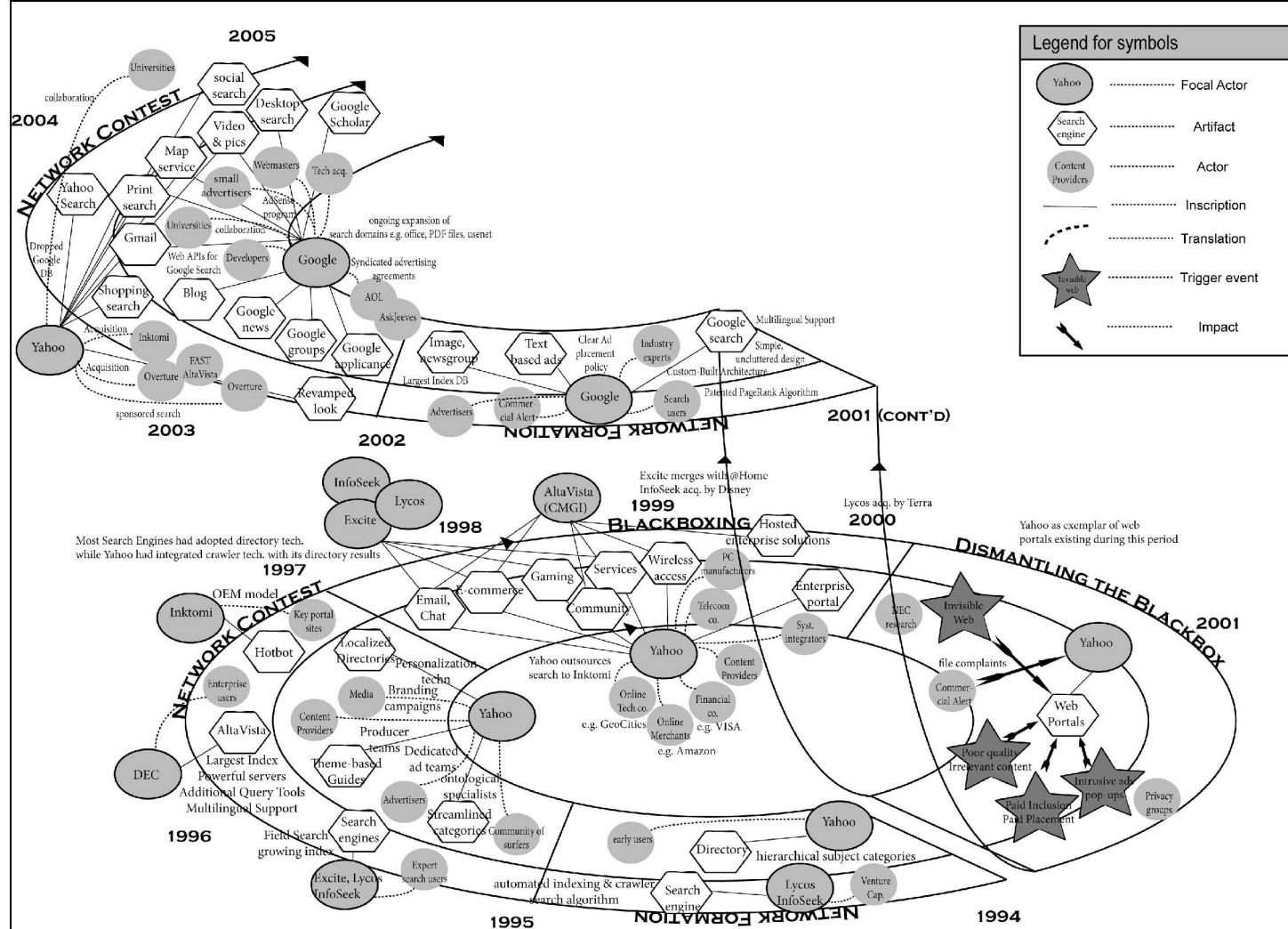
APPENDIX A

Fig. A1 Spiral Process Model of Technological Evolution: Web Browser



APPENDIX

Fig. A2 Spiral Process Model of Technological Evolution: Web Search





## References

- Abernathy, W.J., and Utterback, J.M. "Patterns of Industrial Innovation," *Technology Review* (80:7) 1978, pp 40-47.
- Agarwal, R., and Sambamurthy, V. "Principles and models for organizing the IT function," *MIS Quarterly Executive* (1:1) 2002, pp 1-16.
- Akrich, M., Callon, M., and Latour, B. "The Key to Success in Innovation Part II: The Art of Choosing Good Spokespersons," *International Journal of Innovation Management* (6:2) 2002, pp 207-225.
- Akrich, M., and Latour, B. "A Summary of a Convenient Vocabulary for the Semiotics of Human and Nonhuman Assemblies," in: *Shaping Technology, Building Society: Studies in Sociotechnical Change*, W. Bijker and J. Law (eds.), MIT Press, Cambridge, Mass, 1992, pp. 259-264.
- Anderson, P., and Tushman, M.L. "Technological Discontinuities and Dominant Designs: a Cyclical Model of Technological Change.," *Administrative Science Quarterly* (35:4), December 1990, pp 604-633.
- Angel, K. *Inside Yahoo!: Reinvention and the road ahead* John Wiley & Sons, New York, New York, 2002.
- Athavaley, A. "Mozilla Creates Unit To Promote Firefox," in: *The Washington Post*, 2005, p. D05.
- Battelle, J. *The Search: How Google and Its Rivals Rewrote the Rules of Business and Transformed Our Culture* Penguin Group, New York, New York, 2005.
- Benford, R.D., and Snow, D.A. "Framing processes and social movements: An overview and assessment," *Annual Review of Sociology* (26) 2000, pp 611-639.
- Berners-Lee, T. *Weaving the web* HarperCollins, New York, NY, 1999.
- Bijker, W.E. *Of Bicycles, Bakelites, and Bulbs: Towards a Theory of Sociotechnical Change* MIT Press, Cambridge, MA, 1995.
- Bijker, W.E., Hughes, T.P., and Pinch, T.J. *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* MIT Press, Cambridge, MA, 1987.
- Boyatzis, R. *Transforming Qualitative Information: Thematic Analysis and Code Development*. Sage, Thousand Oaks, CA, 1998.
- Bray, H. "Netscape unveils browser," in: *The Boston Globe*, 1998, p. D4.
- Callon, M. "Some Elements of a Sociology of Translation: Domestication of the Scallops and the Fishermen of St. Brieuc Bay," in: *Power Action and Belief: A New Sociology of Knowledge*, J. Law (ed.), Routledge, London, 1986, pp. 196-233.
- Callon, M., and Latour, B. "Unscrewing the big leviathan: How do actors macrostructure reality," in: *Advances in social theory and methodology toward an integration of micro and macro sociologies*, K. Knorr and A. Cicourel (eds.), Routledge and Kegan Paul, London, 1981, pp. 277-303.
- Cheng, K. "Selling simplicity.," in: *Adweek*, 1999, p. 58.
- Corcoran, E. "Netscape Offers Web Browser for Free," in: *The Washington Post*, 1998, p. G03.
- Cusumano, M.A., and Yoffie, D.B. *Competing on Internet Time: Lessons from Netscape and Its Battle with Microsoft* The Free Press, New York, NY, 1998.
- Dosi, G. "Technological Paradigms and Technological Trajectories: A Suggested Interpretation of the Determinants and Directions of Technical Change," *Research Policy* (11) 1982, p 147-162.
- Dougherty, D. "Understanding New Markets for New Products," *Strategic Management Journal* (11:Special Issue: Corporate Entrepreneurship) 1990, pp 59-78.
- Elsbach, K.D. "Managing Organizational Legitimacy in the California Cattle Industry - the Construction and Effectiveness of Verbal Accounts," *Administrative Science Quarterly* (39:1), Mar 1994, pp 57-88.
- Faraj, S., Kwon, D., and Watts, S. "Contested artifact: technology sensemaking, actor networks, and the shaping of the Web browser," *Information Technology & People* (17:2) 2004, pp 186-209.
- Farrell, N. "MS Stung By Web Fragmentation Charge," in: *Network News*, 2000, p. 8.
- Festa, P. "Browser Campaign Slams IE," in: *CNET News.com*, 2004a.
- Festa, P. "Mozilla, Gnome mull united front against Longhorn," in: *CNET News.com*, 2004b.
- Festa, P. "Microsoft yielding to IE standards pressure?," in: *CNET News.com*, 2005.

- Garud, R., Jain, S., and Kumaraswamy, A. "Institutional entrepreneurship in the sponsorship of common technological standards: The case of Sun Microsystems and Java," *Academy of Management Journal* (45:1), February 2002, p 196-214.
- Garud, R., Jain, S., and Phelps, C. "Organizational linkages and product transience: New strategic imperatives in network fields," *Advances in Strategic Management* (15) 1998, pp 205-237.
- Garud, R., and Kumaraswamy, A. "Technological and Organizational Designs for Realizing Economies of Substitution," *Strategic Management Journal* (16) 1994, pp 93-110.
- Garud, R., and Rappa, M. "A socio-cognitive model of technology evolution: The case of cochlear implants," *Organization Science* (5:3), August 1994, pp 344-362.
- Gatignon, H., Tushman, M.L., Smith, W., and Anderson, P. "A structural approach to assessing innovation: Construct development of Innovation Locus, Type, and Characteristics," *Management Science* (48:9), September 2002, pp 1103-1122.
- Glaser, J., and Strauss, A. *The discovery of grounded theory* Aldine, Chicago, 1967.
- Goffman, E. *Frame Analysis: An essay on the organization of the experience* Harper Colophon, New York, 1974.
- Greene, J., Reinhardt, A., and France, M. "A New World For Microsoft?," in: *BusinessWeek*, 2004, p. 44.
- Griffith, T.L. "Technology Features as Triggers for Sensemaking," *Academy Management Review* (24:3) 1999, pp 472-488.
- Hane, P.J. "Northern Light Receives \$35 Million in Funding," in: *Information Today*, 1999, p. 1.
- Hanseth, O., and Monteiro, E. "Inscribing behavior in information infrastructure standards," *Accounting, Management, and Information Technology* (7:4) 1997, pp 183-211.
- Hughes, T.P. "The evolution of large technological systems," in: *The social construction of technological systems*, W.E. Bijker, T.P. Hughes and T.J. Pinch (eds.), MIT Press, Cambridge, Mass., 1989, pp. 51-82.
- Kaplan, S., and Tripsas, M. "Thinking about technology: how cognitive frames shape technical change," in: *Sloan School of Management*, MIT, Boston, 2005, p. 50.
- Katz, F. "Netscape 6 flashy, but still needs work," in: *The Denver Post*, 2000, pp. E-09.
- Kopytoff, V. "Yahoo cements UC partnership," in: *The San Francisco Chronicle*, 2005, p. C1.
- Krantz, M. "Start Your Engines," in: *Time South Pacific*, 1998, p. 53.
- Krippendorff, K. *Content analysis: An introduction to its methodology* Sage Publications, Thousand Oaks, CA, 2004.
- Krol, C. "Yahoo! turns 10, absorb Overture," in: *B to B*, 2005, p. 3.
- Langley, A. "Strategies for theorizing from process data," *Academy Management Review* (24:4) 1999, pp 691-710.
- Latour, B. *Science in Action: How to Follow Scientists and Engineers Through Society*. Harvard University Press, Cambridge, MA, 1987.
- Latour, B. *Pandora's hope: essays on the reality of science studies*, (2nd ed.) Harvard University Press, Cambridge, MA, 1999.
- Law, J. "On the Methods of Long-Distance Control: Vessels, Navigation and the Portuguese Route to India," in: *Power, Action and Belief. A New Sociology of Knowledge*, J. Law (ed.), Sociological Review Monograph, Keele, 1986, pp. 234-263.
- Law, J. "Notes on the theory of the actor-network: Ordering, strategy, and heterogeneity," Centre for Science Studies, Lancaster University, Lancaster LA1 4YN, 1992.
- Lundquist, E. "The Alta Vista Lesson: Search Still Counts.," in: *PC Week*, 1999, p. 94.
- Markoff, J. "A Growing Rivalry Derails AOL Talks for Microsoft Deal," in: *New York Times*, 2001, p. 1 Col. 1.
- Markoff, J. "Mozilla Plans Faster Growth For Its Browser," in: *The New York Times*, 2005, p. 5.
- Miles, M.B., and Huberman, A.M. *Qualitative Data Analysis: An Expanded Sourcebook* Sage, Thousand Oaks, CA., 1994.
- Milgrom, P., and Roberts, J. "Complementarities and fit: Strategy, structure and organizational change in manufacturing," *Journal of Accounting and Economics* (19) 1995, pp 179-208.
- Moody, G. "Internet: Learning to crawl all over the web," in: *The Guardian*, London, 1994, p. 5.
- Nelson, R.R., and Winter, S.G. "In search of a useful theory of innovation," *Research Policy* (6) 1977, pp 36-76.
- Network News "Battle Of The Web Browsers Looms As Mozilla Is Unleashed," in: *Network News*, 2002, p. 3.

- Orlikowski, W.J. "Using Technology and Constituting Structures: A Practice Lens for Studying Technology in Organizations," *Organization Science* (11:4) 2000, pp 404-428.
- Orlikowski, W.J., and Gash, D.C. "Technological frames: Making sense of information technology in organizations," *ACM Transactions on Information Systems* (12:2), April 1994, pp 174-207.
- Orlikowski, W.J., and Iacono, C.S. "Research commentary: desperately seeking the 'IT' in IT research," *Information Systems Research* (12:2) 2001, pp 121-134.
- Pontin, J. "Dinner with the mind behind the mind of God," in: *Red Herring*, 2002, p. 28.
- Rao, H. "The social construction of reputation: Certification contests, legitimation, and the survival of organizations in the American automobile industry," *Strategic Management Journal* (15:Special Issue: Competitive Organizational Behavior) 1994, pp 29-44.
- Rapoza, J. "IE 7 Beta Narrows Gap Between Browsers," in: *eWeek*, 2005, p. 42.
- Rindova, V.P., and Kotha, S. "Continuous "Morphing": Competing Through Dynamic Capabilities, Form, and Function," *Academy of Management Journal* (44:6) 2001, pp pg. 1263-1280.
- Rosenkopf, L., and Tushman, M.L. "The Coevolution of Technology and Organization," in: *Evolutionary Dynamics of Organizations*, J.A. Baum and J.V. Singh (eds.), Oxford University Press, New York, 1994, pp. 403-424.
- Rosenkopf, L., and Tushman, M.L. "The Coevolution of Community Networks and Technology: Lessons from the Flight Simulation Industry," *Industrial and Corporate Change* (7) 1998, pp 331-346.
- Sacharow, A. "Search for tomorrow," in: *Adweek Western Edition*, 1997, p. 61.
- Salkever, A., and Prasso, S. "Search Engines: Leading Us Astray?," in: *Business Week*, 2001, p. 8.
- Schatz, B.R. "Information retrieval in digital libraries: Bringing search to the Net," *Science* (275:January), 17 January 1997, pp 327-334.
- Schwartz, B. "Explorer upgrade lets you chart a simpler course through the Net," in: *USA Today*, 1999, p. 6D.
- Sherman, C. "The Future of Web Search," *Online* (23:3), May/June 1999, p 54.
- Sherman, C., and Price, G. *The Invisible Web* CyberAge Books, Medford, NJ, 2001.
- Sproull, L.S., and Goodman, P.S. *Technology and organizations: Integration and opportunities* Jossey-Bass, San Francisco, 1990.
- Stone, B. "Driving the Web engines," in: *Newsweek*, 1998, p. 82.
- Swanson, E., and Ramiller, N. "The organizing vision in information systems innovation," *Organization Science* (8) 1997, pp 458-474.
- Symantec "Symantec Internet Security Threat Report Vol. VII," Symantec Corporation, Cupertino, CA, pp. 1-92.
- Tuomi, I. "Internet, Innovation, and Open Source: Actors in the Network," Association of Internet Researchers, Lawrence, Kansas, 2000.
- Tushman, M.L., and Anderson, P. "Technological Discontinuities and Organizational Environments," *Administrative Science Quarterly* (31) 1986, pp 439-465.
- Van de Ven, A., and Garud, R. "A framework for understanding the emergence of new industries," *Research on Technological Innovation, Management and Policy*:195-225) 1989.
- Van de Ven, A.H. "Running in packs to develop knowledge-intensive technologies," *MIS Quarterly* (29:2), June 2005, pp 365-378.
- Van de Ven, A.H., Polley, D.E., Garud, R., and Venkataraman, S. *The Innovation Journey* Oxford University Press, New York, 1999.
- Van de Ven, A.H., and Poole, M.S. "Methods for studying innovation development in the Minnesota Innovation Research Program," *Organization Science* (1:3) 1990, pp 313-334.
- Van House, N.A. "Digital Libraries and Collaborative Knowledge Construction," in: *Digital Library Use: Social Practice in Design and Evaluation*, A.P. Bishop, B.P. Buttenfield and N.A. Van House (eds.), MIT Press, MA, 2003.
- von Burg, U. *The Triumph of Ethernet* Stanford University Press, Stanford, California, 2001.
- Watson, R., and Harrington, A. "Gates empire strikes back," in: *The Herald*, Glasgow, 2000, p. 2.
- Weick, K. "Technology as equivoque: Sensemaking in new technologies," in: *Technology and organizations*, P.S. Goodman and L.S. Sproull (eds.), Jossey-Bass, San Francisco, 1990.
- Welles, E. "All the right moves," in: *Fortune Small Business*, 2002, p. 24.