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The complex search process of invention

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ABSTRACT

We inductively develop a process model of individual search in the context of technological invention, an important aspect of economic development that is also fundamental to the success of many organizations. Using an extensive archival content analysis of notable inventors we find that the search and discovery process of invention is inherently complex, non-linear, and disjointed. Successful inventors are skilled at managing these complex systems, receptive to feedback, and able to revisit and change course. Our search model includes a stimulus, net casting for information, categorizing that information, linking unrelated ideas, and discovery. Our findings articulate the search process as a complex progression through a series of simple stages. As such, the study contributes to our understanding of complexity and the complex systems view of the invention process.

1. Introduction

The concept of search is fundamental to both organizational learning (e.g. Huber, 1991) and behavioral theories of the firm (Cyert and March, 1963). Among other things, individuals within a firm search for information and answers that will enable them to decide which actions to take (e.g. Derfus et al., 2008), close gaps between their actual and aspirational performance (e.g. Levinthal and March, 1981), and develop new innovations (e.g. Katila and Ahuja, 2002) and find new opportunities (Kornish and Ulrich, 2010). While we know a great deal about how organizations start, stop and allocate resources to search, our knowledge of individual search processes is limited. That is, what we do know about the topic is focused almost entirely at the organizational level of analysis. Thus, how individuals search for the ideas that they discover is not well-understood. By focusing on the search routines and the discovery process of inventors, this study bridges this research gap and provides a foundation for further empirical study of search processes in other contexts and levels of analysis.

Technological invention is an important element for economic development as well as the success of technology-based organizations. Thus, understanding the process through which individuals develop new technologies is central to organizational as well as to more macro-focused research. In particular, the processes through which individuals search for new technological inventions – that is, look to the environment to improve current technology and products (Nelson and Winter, 1982: 210) – have drawn increasing interest in recent organization research. Drawing from behavioral theory and organizational learning perspectives, researchers have studied what triggers search (Greve, 2003; Greve and Taylor, 2000; Singh et al., 2010), what the optimal processes of search are (Grimpe and Sofka, 2009; Levinthal and March, 1981; He and Wong, 2004), and when searchers decide to stop searching (Cyert and March, 1963). The main findings of this research show that both problems and opportunities initiate search, and that search stops when a satisfactory result in discovered (Greve and Taylor, 2000). Researchers have also proposed that search proceeds in a problem-solving or hypothesis-testing fashion (Winter, 1984). At the same time, search is constrained by cognitive and physical limitations: cognitive frames (Gavetti and Levinthal, 2000) and limited resources (Helfat, 1994) often restrict search range to include only local environments.

In this study, we construct an inductive case-based model of the search and discovery process. Our focus is on the specific case of new technological inventions. To construct the model, we employ an archival content analysis of first person accounts of ten notable technology inventors. Using the insights from each inventor and triangulating across the inventors, eight common themes of the search and discovery process emerge. We structure and refine emerging themes analyzing and reanalyzing the data, looking for patterns, and organizing them (Eisenhardt, 1989). This iterative process leads to several important findings. We find that the search and discovery process of technological invention is inherently complex: nonlinear and disjointed rather than linear and cumulative. Moreover, the data show that successful inventors

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are skilled at managing such obscurity: they make complex systems simple by abstracting out the unnecessary and minor, and use negative feedback to start over and change course. Thus, they undertake a complex progression through a seemingly simple set of stages. Based on our findings, we develop theory and present a model of search that illustrates it as being comprised of underlying routines including casting for information and re-categorizing that information. Further, we also find that inventor's new ideas lie at the intersection of existing, yet seemingly disparate, landscapes that requires them to manage interdependencies and react to a complex system of continuously changing internal and external factors.

The study provides several contributions to search and complexity theories. First, we highlight the search process of individuals. Indeed, the traditional focus of research on the concept of search has been on the organization. Second, the study contributes to the complex systems view on invention at the individual level (Arthur, 2009). This represents a contribution to the complex systems literature both in terms of the context of invention and level of analysis. We highlight the skills of interpreting, managing, and utilizing feedback that inventors in our sample used during their search process. Finally, unlike extant conceptual models found in the literature, we present grounded theory and an empirically derived process model of individual search that can begin to enable researchers to examine more closely search processes, versus using distal proxies of search, of both individuals and organizations, such as patent search, R&D expenditures or number of scientists.

2. Literature review and research background

The concept of search has been examined in a number of academic disciplines. However, there has been a relative dearth of studies that seek to study the actual routines and the process of search. For example, economists have elicited mathematical models that illustrate the degree to which individuals search for jobs (Lipman and McCall, 1976) and new technologies (e.g. Jensen, 1982; Reinganum, 1982). Similarly, marketing researchers have used economic and mathematical models to examine consumers' search for low prices (e.g. Meyer, 1997; Miller, 1993). Marketing research has also examined the extent to which individuals will search before selecting consumer goods (e.g. Mitra et al., 1999; Stewart et al., 1989). In general, the findings in these areas focus on the rules individuals use to decide when additional search is necessary or not.

Organization theory research on the topic of search draws from a learning foundation (March and Simon, 1958). Thus, learning outcomes as a result of search behavior have been examined in a variety of contexts such as the selection of exchange partners (Rangan, 2000), acquisition performance (Katila and Ahuja, 2001), technological inventions (Fabrizio, 2009; Rosenkopf and Nerkar, 2001; He and Wong, 2004), and product competition (Greve and Taylor, 2000). Researchers in this area argue that firms search for information to generate potential alternatives in their quest to innovate (Rosenkopf and Nerkar, 2001), solve problems, and reduce organizational performance gaps (Huber, 1991; March, 1991). In his seminal paper, March (1991) argued that firms must balance their far reaching exploratory search with exploitative search, the latter of which more closely utilizes their current knowledge, in order to maximize their learning and the opportunities they discover from this learning (Gupta et al., 2006). Others have expanded on this notion to include a more varied set of locations or terrains (Rivkin and Siggelkow, 2007). For example, search can deviate in topography (Nelson and Winter, 1982), depth and scope (Katila and Ahuja, 2002) and in organizational and technological boundary spanning characteristics (Rosenkopf and Nerkar, 2001).

While research in the organizations literature has focused on the search terrain, search context, and the importance of search at the organizational level, there has been less attention to the actual search *processes* and the underlying routines that organizations or individual organization members use to search. One reason why it has been difficult to study individual search processes is that search oftentimes occurs over a long period of time, in the case of the search for new technological inventions this can mean a decade or more. As a consequence, existing individual level search process research generally falls into two categories: one claiming that search is illusory and needs no explanation and the other claiming that it is mysterious and permits no explanation (Schon, 1963).

In this study, we utilize an extensive historical content analysis of notable technology inventors to inductively develop theory about the search process and propose a model of search routines and processes at the level of the individual inventor. While there exists a conceptual literature on search process, we are unaware of other empirical attempts to inductively model the search process. Thus, in the discussion section, we compare our induced model of individual search to conceptual models of invention as well as related areas of creativity, decision-making, and problem solving. We identify common elements and important differences between our model of search and these conceptual models in an effort to further our understanding of the process of search used in the discovery of inventions.

3. Method

Because of the dearth of empirical efforts to model the search process, it was necessary to undertake a grounded, theory building approach. Thus, the methodology used in this study is a qualitative, inductive, archival, content analysis of historical first-person documents and quotations of ten notable inventors. According to Smith (2000), this type of approach allows categories (stages) to emerge from material without the influence of preconceptions. Throughout our study, we closely followed the guidelines for content-analytic research proposed by Smith (2000) and Eisenhardt (1989).

Content analysis is used to extract information from qualitative material. It can be performed in a variety of situations including when participants are aware they are being studied and also when they are not. It can also be used with both verbal or written materials and documents. The content material is analyzed systematically and objectively to identify the characteristics of interest (Smith, 2000). In this study, we analyzed historical documents in an attempt to elicit any recurring patterns of activity as it applies to the search and discovery process of invention. These patterns will be used to develop a model of the search process.

More specifically, we employed archival reading and content analysis of first person accounts of the invention process of ten notable inventors. In an effort to keep the data collection manageable yet ensure an appropriate level of first person documentation, we randomly selected ten of the inventors interviewed and quoted by Brown (1988) in his well-known book *Inventors at Work*. These individuals are: Marvin Camras (inventor of magnetic recording tape), Gordon Gould (inventor of the Laser), Wilson Greatbatch (inventor of the implantable pacemaker), Marcian E. "Ted" Hoff (inventor of the microprocessor), Raymond Kurzweil (inventor of the first commercial application of artificial intelligence, the piano/synthesizer), Paul MacCready (inventor of the Gossamer Condor, the first vehicle to fly on human power), Stanford Ovshinsky (inventor of Ovonic devices), Harold Rosen (inventor of the spin stabilized geo-synchronous satellite), Steve Wozniak (inventor of the first truly personal computer, the Apple II), and Nat Wyeth (inventor of the ubiquitous plastic soda bottle).

We performed an exhaustive library search on the ten inventors to ensure replication, completeness, and corroboration of our