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Thinking about technology: understanding the role of cognition and technical change

Sarah Kaplan and Mary Tripsas

MIT-IPC-03-007

December 2003

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Working paper, December 2003

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Abstract

Scholars of technical change have long been interested in understanding the ways in which new technologies shape and are shaped by firms and industries. Much attention has been focused on the three fundamental questions in the field – How do technologies evolve? How do producers respond to technical change? How do users adopt and adapt to new technologies? The phenomena represented by these questions are complex, in large part because of the high degree of uncertainty inherent in periods of technical change. It seems likely in these situations that the actors' cognitive frames of the technology and environment should play a critical role in determining outcomes. Yet, despite an increasing interest in cognition in management research, cognitive perspectives have made only small inroads into an understanding of these questions individually and as they relate to each other. In this paper, we develop a model of producers and users as interpretive systems that interact to shape the evolution of technology. We then illustrate this model using a case study of the evolution of Personal Digital Assistants (PDAs).

Key words: frames, cognition, technical change, technology strategy, adoption of technology

What is a Palm Pilot anyhow? It is certainly more than its primary function as an electronic datebook. But is it a piece of glitzy consumer electronics, moving off the shelves like Walkman and Gameboy? Is it like a PC operating system, competing with Microsoft Windows, only smaller? Or it is a new kind of communications device justifying a monthly bill for service, making Nokia and Ericsson tremble? If it were a consumable, users would throw the old ones away as soon as new ones came out with sexier features. But you don't need to spend $450 for a color screen for your datebook. If Palm were a platform, new killer applications would entice users to embrace new machines. If it were a new communications device, the wireless bill would come from a phone company. It must be something else.

-- Jordan Pollack,
Professor of Computer Science, Brandeis University
and Founder of Thinmail, an e-mail service for wireless devices[1]

Introduction

During periods of ferment, new technology often creates widespread confusion, in particular when the technology results in new product categories or revolutionizes old ones. In such situations, producers and users as well as a broad range of other players, such as distributors, complementary producers, and regulators are surrounded by uncertainty: What exactly is the technology? How should it be evaluated? What should it be compared to? How will it evolve?

Scholars of technical change have long been interested in understanding the ways in which these issues are resolved – how new technologies shape and are shaped by producers and users. Much attention has been focused on three fundamental questions in the field: How do technologies evolve (Bijker, Hughes, and Pinch 1987; Dosi 1982; Klepper 1997; Utterback 1994)? How do established producers respond to technical change (Christensen and Bower 1996; Henderson and Clark 1990; Tushman and Anderson 1986)? How do users adopt and adapt to new technologies (Orlikowski 1992; von Hippel 1987)? The phenomena represented by these questions are complex, in large part because of the high degree of uncertainty inherent in periods of technical change. It seems likely in these situations that the actors' interpretations of the

[1] "Manager's Journal: Can Palm Pilot Be More Than a Datebook?" Wall Street Journal, July 9, 2001, p. 28.

technology and environment should play a critical role in determining outcomes. It is precisely these underdetermined situations (Tushman and Rosenkopf 1992), where the characteristics are not clear enough to dictate action, that the actors' frames of the environment, not the "objective" features of the situation become the basis of strategic choice and action (Finkelstein and Hambrick 1988). Yet, despite an increasing interest in cognition in management research (Huff 1990a; Walsh 1995), cognitive perspectives have made only small inroads into an understanding of these questions individually and as they relate to each other.

In this paper, we apply a cognitive lens to the evolution of technology. We integrate the literature on managerial cognition with that on technological change in order to develop a more intricate understanding of technological evolution. We develop a co-evolutionary model of technology and organizations in which the interactions between the interpretive systems of producers and users shape technical change. In this model, the environment and technological artifacts are perceived by a variety of actors. These perceptions are, by necessity, simplified representations of a more complex environment (March and Simon 1958) and are influenced by cognitive frames[2] that encode the history of the individual and the firm, shape the options considered, the decisions made and the actions taken. Further, this is a recursive process. Actions by producers and users interact, influencing the ongoing development of frames, and also feeding back to the environment and the evolving technological artifact. Thus, a

[2] Cognition means many different things to many people, and even in the context of managerial research, the views cover a broad spectrum. Perceptions have been represented in research as *mental models* (Johnson-Laird and Shafir 1993; Senge 1990), *cognitive maps* (Axelrod 1976), *thought worlds* (Dougherty 1992) or one of more than 70 different terms used in the management community (Walsh 1995). The managerial cognition literature specifically has tended to draw on more social psychological notions of cognition, or often avoids definitions by referring simply to "beliefs" or "interpretations." In this paper, we will use the term "frames" which comes from the symbolic interactionist tradition (Goffman 1974) and is most consistent with our understanding of the importance of interactions among actors' beliefs in shaping technological evolution.

technological trajectory represents a resolution of both a variety of competing technologies and competing frames.

This paper makes two specific contributions to the literature on technical change. First, we highlight the importance of both producer and user interpretive systems, and in particular, the interactions between them, in the shaping of technology. We thus extend prior work on the evolution of technology that is either silent about the role of cognitive framing (e.g. Dosi 1982; Tushman & Anderson, 1986; Utterback 1994) or considers only the interpretive systems of one class of actors (e.g., Garud and Rappa's (1994) socio-cognitive model, which focused on the scientists within competing firms). Second, we argue that interactions between interpretive systems are often not simply passive, but can also comprise purposeful efforts to shape the frames of others. These interactions can result in shared frames around the meaning of new technologies. This model opens the door to the idea that firms can potentially create competitive advantage by taking purposeful, strategic action in order to influence the interpretive frames of other actors about a new technology. To illustrate our model, we describe the evolution of the Personal Digital Assistant (PDA), where interpretive frames have played an important role in the evolution of the technology and market.

Technical change: potential for cognitive explanations

Traditional evolutionary models of technical change, in essence extensions of Kuhnian (Kuhn 1970) notions of scientific trajectories, are quite deterministic. They posit that following a technological discontinuity, technical variation and selection take place in an era of ferment, with selection leading to the retention of a dominant design, followed by a period of incremental technical change, and ultimately disruption by another technological discontinuity as the cycle repeats itself (Anderson and Tushman 1990). In line with the organizational learning literature, once a dominant design has emerged, technological progress is guided by a path dependent learning process in which a firm's adaptive intelligence is limited (Levinthal and March 1993; Levitt and March 1988/1996). Firms engage in local search, constrained by existing organizational routines and problem solving heuristics associated with the dominant design (Nelson and Winter 1977; Nelson and Winter 1982). For instance, Dosi (1982) defines a technological trajectory "as the pattern of 'normal' problem solving activity (i.e. of 'progress') on the ground of a technological paradigm" (p. 152), and Rosenberg (1969) describes technical change as meant to progress in one "painfully obvious" direction.

Incremental improvements to a technology are viewed as having natural limits that are determined by the nature of the technology or problems of scale and complexity over time (Foster 1986; Sahal 1981). When a technology has reached its limits, a new discontinuous innovation is likely to invade an industry, sparking a new era of ferment. Much of this literature is predicated on the Schumpeterian view that technological discontinuities are exogenously given and can be known as they occur: a breakthrough technology creates the discontinuous change (Dosi 1982).

We argue that the inherent uncertainty surrounding new technology, however, makes it difficult to identify discontinuities *ex ante*. The specific nature of a discontinuity, the dimensions along which it will have impact, and the appropriate path of action are very rarely obvious in advance. Producers, users and other relevant actors are unsure about the capabilities of the technology, how it will be put to use, and how to categorize it relative to existing technologies and markets. Players thus need to "make sense" of their situation in an era of technological ferment before they can act (Weick 1990; Weick 1995), inviting the idea that existing cognitive frames play a significant role in shaping responses, and suggesting that these very interpretations and actions can, in a co-evolutionary manner, shape the direction of the technical change itself. Yet, while managerial cognition is receiving increasing attention in management research (Huff 1990b; Walsh 1995), the floodlights have not yet been pointed fully on this particular setting where, ironically, frames may be most likely to matter.

At its heart, framing is about the way individuals perceive, filter and conceptualize information (Tenbrunsel, Galvin, Neale, and Bazerman 1996; Weick 1990). These perceptions have been shown to form the foundation of decisions and action in individuals and organizations (Daft and Weick 1984; Goffman 1974). The examination of cognition in the managerial arena goes back at least to March and Simon (1958) who argued that everyone in firms brings a certain cognitive foundation, a set of "givens," to any management decision – assumptions about the future, knowledge about alternatives and a view of the consequences of pursuing each alternative. This foundation is based on simplified representations of the information environment that must be made because of cognitive limits in the face of an information environment that cannot be known in all of its complexities.

The concept of bounded rationality has led to a rapidly growing literature in the strategic management field, in which scholars argue that frames are the basis of strategic action (Hambrick and Mason 1984; Huff 1990a; Kiesler and Sproull 1982; Porac, Thomas, and Baden-Fuller 1989; Prahalad and Bettis 1986). While frames have their origin in the individual, management scholars have found it useful to conceptualize frames as the property of both individuals and collectives such as groups or coalitions (Dougherty 1992), firms (Prahalad and Bettis 1986) strategic groups of firms (Peteraf and Shanley 1997; Reger and Huff 1993), and industries (Porac, Thomas, and Baden-Fuller 1989). In this paper, we find it useful to expand beyond the psychological notion of bounded rationality to a more sociological conception.

Specifically, we draw on Goffman's (1974) notion of frames or schemata of interpretation because of its foundation in theories of interactions among actors and its use as a means to link micro and macro changes.

While frames can exist around all aspects of the information environment, for the purposes of an analysis of technical change, we focus on frames about: the nature of the technical change (incremental or discontinuous); whether the change is a threat or opportunity (Dutton and Jackson 1987; Jackson and Dutton 1988); the relevant dimensions of merit upon which to evaluate the technology (Das and Das 2001; Tushman and Rosenkopf 1992), and the scope of the impact, including how the technology is envisioned to evolve and how it should be incorporated into the firm. Other frames about the environment include those of the competitive set (Lant and Baum 1995; Peteraf and Shanley 1997; Porac, Thomas, and Baden-Fuller 1989; Reger and Huff 1993) and the relevant customers and their needs (Christensen and Bower 1996).

A limited number of case studies provide some provocative data regarding the importance of managerial cognition in shaping firm response to technical change in areas as diverse as railroads (Barr, Stimpert, and Huff 1992), digital imaging (Tripsas and Gavetti 2000), and online newspapers (Gilbert 2002). Empirical analyses of technological trajectories also begin to point the finger at interpretive issues such as attention and "taken for granted" knowledge. Vincenti (1994) showed that retractable landing gear for airplanes was not immediately recognized as a discontinuity nor a potential dominant design relative to "pants-type" fixed landing gear by many in the aircraft industry. And, Henderson (1995) suggests that, in photolithography, the life cycle was more a cognitive structure than a purely technical set of limits.

In this vein, social construction of technology scholars have challenged the deterministic view of technological evolution, suggesting that the development of a technology is shaped by the efforts of social groups in the environment to define and solve problems in “a fierce fight to construct reality” (Latour and Woolgar 1979: 243), reality being the consequence of the resolution of the dispute rather than the driver of the resolution. In this line of thinking, closure results not from the inherent limits of the technology but from the emergence of a consensus about the nature of the technology (Pinch and Bijker 1987). However this literature does not explicitly examine the specific role of frames, with the noted exceptions of Bijker’s (1987) study of the early history of plastics and Garud and Rappa’s (1994) analysis of the emergence of cochlear implant technologies. Garud and Rappa in particular highlight the importance of researcher beliefs and evaluation routines which co-evolve alongside the technical artifact.

These studies offer a compelling glimpse at the power a cognitive explanation might bring to understanding the evolution of technology. In this paper, we extend this beginning by developing a model that explores the interactions, both passive and purposeful, between the interpretive systems of producers and users and how they affect the evolution of technology. The model addresses the origins of frames, how frames are enacted in producer and user interpretive systems and how this interaction shapes technical change.

A co-evolutionary model of cognitive frames and technical change

To develop our model, we draw on several earlier efforts to link frames with firm behavior (Daft and Weick 1984; Foster and Kaplan 2001; James 2000; Kiesler and Sproull 1982; Ocasio 1997). These models all focus on producer firms and share several elements: an information environment perceived by the actors; decision makers and their frames of reference; a decision making process that involves some form of scanning, noticing, interpreting, deciding and acting; other contextual factors such as group dynamics; and, often, a series of feedback loops that link actions and outcomes to changes in the environment or in frames of reference. We synthesize these models in Figure 1. In the rest of this paper, we amplify these earlier models by considering the role of both producers and users as interpretive systems that interact with each other to shape outcomes. In addition, we focus on both the passive and purposeful interactions between these different sets of actors and emphasize their recursive dynamics.

-- Insert Figure 1 about here --

Information environment and technology artifact. The information environment comprises a diverse range of factors such as competitor and supplier activities, government policy and regulation, macroeconomic and demographic trends, customer needs, and resources and capabilities (internal and external to the firm). We have separately highlighted technological artifacts themselves as an object of perception (and ultimately something that will be shaped by the outcomes of producer and user activities). We use an expansive definition of a technological artifact. It can be understood as an actual, existing product, a patent, or a scientific publication that represents the embryo of a future technology, as well as a technical capability or decision making heuristic.

The important aspect of this information environment is that it does not transmit clear and easily recognizable signals to producers about market needs nor to users about the nature of the technology. Uncertainty exists about the performance trajectory of the technologies, the cost of developing them, their ultimate uses, and the size of the potential market, among other things.

Indeed, it is this very uncertainty that invites an explanation based in framing to the evolution of technology.[3]

The origin of frames. Frames do not simply spring up randomly but rather are the encoding of previous individual and organizational experience. History matters in this model, though we take a quite broad definition of history that includes individual career histories, individual and group demographics, and firm accumulations of capabilities. Any individual, team, firm, or industry will have multiple different histories that generate knowledge accumulations (Bourdieu 1977; Carlile 2002) and can have reinforcing or countervailing effects on one other as they are encoded into frames of reference.

For instance, at the individual and group levels of analysis, Dougherty (1992) shows that people in different functions (such as R&D or marketing) have different "thought worlds" that lead to conflicts of interpretation during new product development projects. Extending this idea further, demographic measures have often been used as proxies for cognitive frames (Ancona and Nadler 1989; Virany and Tushman 1986; Wiersema and Bantel 1992). Tushman and his collaborators (Tushman and Rosenkopf 1996; Virany, Tushman, and Romanelli 1992), for example, have found that top management team demographics influence a firm's ability to successfully navigate major discontinuities. Personal and team histories, as embodied in

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[3] We will not enter here into the ontological debate about whether this framing process addresses an objective, pre-given environment or whether this reality is more socially constructed. By arguing that the cognitive frame more or less accurately interprets information, scholars are making the implicit assumption that the mapping process "distorts" some objective reality (Hambrick and Mason 1984; Prahalad and Bettis 1986; Sutcliffe 1994). On the other hand, social constructionists would take issue with this more deterministic view, arguing that cognitive maps don't represent a underlying reality but rather construct it (Bougon 1992; von Krogh and Roos 1996). We believe some middle ground may be the most relevant in studies of technology. While we cannot argue that there are global realities, it is possible to localize frames within a time and place. The observable frame represents the consensus in the moment (Garud and Rappa 1994; Porac 1997).

demographic characteristics, are thus intimately linked to frames of reference, which shape firm responses to technical change.

A similar link can be made at the firm level of analysis: firm history, embodied in the capabilities the firm has developed, influences the collective frames in an organization. Firm capabilities – essentially accumulations of past experience – affect interpretations about what is relevant and possible for a firm to undertake (Prahalad and Bettis 1986). This paper does not attempt to reify the organization as a cognizer but rather holds as an underlying principle that a collective frame and ultimately a collective decision emerges through the interactions of individuals (Fiol 1994; Spender 1998; Weick and Roberts 1993), in particular under conditions of uncertainty.

History often manifests itself in cognitive simplification processes, such as analogies, that actors use to reduce uncertainty in making decisions (Schwenk 1984). The substantial literature in political science (Neustadt and May 1986) and cognitive psychology (Holyoak and Thagard 1997; Steinbruner 1974) about use of analogies in highly uncertain or unstable settings suggests that cognitive simplification processes could be rich territory for understanding technology questions. Analogies are drawn from individual and collective histories, such as prior projects, past watershed events, or previous success (or failure) models. However, in highly complex environments, these analogies could potentially be oversimplifications and limited in their representativeness (Gavetti, Levinthal, and Rivkin 2003; Kahneman, Slovic, and Tversky 1994).

Producer and user organizations as interpretive system. Frames have their impact as they function in the interpretive system of the organization. We argue that there is an organizational interpretive process that involves both individual and collective engagement in environmental scanning and noticing, interpreting, decision making and acting. Because new technologies are inherently "equivocal" (Weick 1990: 2), they are subject to sensemaking as they are developed and used. Orlikowski and Gash suggest that, "To interact with technology, people have to make sense of it; and in this sense-making process, they develop particular assumptions, expectations, and knowledge of the technology, which then serve to shape subsequent actions toward it" (Orlikowski and Gash 1994: 175). This process is both guided by a set of frames, and in turn, influences the evolution of those frames. Both producers and users hold a set of frames about the technology itself and the relevant environment. In addition, each holds frames about themselves in relation to the technology (See Table 1).

The **first stage** in the interpretive system – scanning – is fundamentally about data collection, which is a function of attention (Ocasio 1997). Because the environmental inputs are potentially infinite, both implicit and explicit choices about what data to collect are critical. Producers might be concerned with questions such as: What is the relevant competitive set? Which customers should we pay attention to? Which technologies should be monitored? Users, on the other hand, might ask: What technologies are relevant to our needs? What measures should we use to evaluate and benchmark performance? These questions will be critical for defining what information enters into the interpretive system.

Cognitive frames can have a significant influence on scanning in a new technological domain. Engineers make a series of choices as they move down the design hierarchy in developing a new product (Clark 1985) and in doing so, the types of questions asked and definition of the problem space are based on the experiences of the past. The needs of existing customers often receive more attention than those of new, emerging segments (Christensen and Bower (1996). Codified in a firm's architectural knowledge (Henderson and Clark 1990), heuristics such as these are difficult to change.

In negotiating new technical environments, firms also look at the activities of members of their competitive set or community, for input (Porac, Thomas, Wilson, Paton, and Kanfer 1995; Wade, 1996). They often mimic the behaviors of these firms (Bogner and Thomas 1993) or use competitive behavior to signal the legitimacy of change (Greve and Taylor 2000). When the environment shifts, however, firms are slow to change their beliefs about which firms constitute competitors. In the financial intermediary industry, for instance, managers used outdated cognitive maps that reflected old industry boundaries even after deregulation transformed the industry (Reger and Palmer 1996). Thus when confronted with technical change, existing frames influence what is noticed in the scanning process.

The **second stage** – interpretation – is where meaning is attributed to these data. Here, producers and users make diagnoses about the relevance and impact of the information. Producers might ask: Is this new technology a threat or opportunity? Will it be competence enhancing or competence destroying? Do these new regulations help or hurt? Does this new entrant pose a credible challenge? This analysis happens at the individual level but also involves a process for achieving a collective, if not consensual, view about the solution. For instance, Polaroid was able to learn about fundamentally new scientific disciplines in digital imaging because management believed that exploring radically new technologies was one of the firm's strongest capabilities (Tripsas and Gavetti 2000). Management thus had a frame that included radically different technologies in a "local" search process. Similarly, when executives in the IT industry perceived their firm to have a greater emphasis on technology, they placed greater value on opportunities related to potential technology alliances and less on their associated risks (Tyler and Steensma 1995).

User interpretations involve a related set of questions: What potential technologies could change the nature of our needs? What might a new technology enable us to do differently? How does this technology relate to products I currently use? Users often do not have the experience to be able to evaluate or understand the attributes of the product (von Hippel 1986). Thus when interpreting data related to a new technology, consumers develop cognitive taxonomies that categorize novel products based on analogies with existing products, mapping familiar features onto the new product (Gentner 1983; Gregan-Paxton and John 1997). User perceptions of new features will also vary depending upon whether the features are core or peripheral to the user (Griffith 1999).

The **third stage** – decision-making and action – is where these interpretations are translated into strategic outcomes. Part of the decision process is the definition of the choice set itself. For the producers, this might include questions such as: Can we really consider breaking out a division to pursue this new technology? Could we reduce investment in a major program by an order of magnitude? Could we consider an earnings-diluting acquisition? For the users: Should we consider using a new technology even if it will be costly to implement? What rules and resources would we have to change to make this technology work? At each stage, the frames held individually and collectively among producers and users define the possibilities and constraints. For instance, pharmaceutical firm top management teams that interpreted the biotechnology revolution as more important to their core pharmaceutical business were more likely to make significant technical investments, in the form of patents and scientific publications, in this emerging new technology (Kaplan, Murray, and Henderson 2003). And print newspapers that perceived the Internet as a threat (vs. an opportunity) were more likely to invest in it (Gilbert 2002).

We argue that this interpretive process is both collective and embedded in a context from which it cannot be separated. It is not a linear, one-time event but rather looping and iterative. Outcomes from the interpretive process affect the environment and alter the technological artifacts. This new environment is then reinterpreted through (potentially altered) frames that produce new outcomes. In contrast to the management of technology literature, which focuses solely on the resolution of technical variation in the life cycle, we explicitly consider the resolution of cognitive variation through this recursive process as well. So in this model, there are not only competing technologies, but also competing cognitions, which play out over time.

The notion that one cannot separate cognition from its social context gives us traction in understanding technology. It suggests that there is no universal technological environment imposing itself on management decision-making nor a technological imperative independent of local decisions that emerge from producer and user interpretive systems.

Interactions among interpretive systems

We posit above that producers and users operate as interpretive systems, with cognitive frames varying significantly depending upon the history of each particular actor (individual or organization). Here we further argue that real understanding of technological evolution comes from examining the interactions among these interpretive systems. We thus view technological evolution as being shaped by the ongoing synthesis of divergent frames, with technical artifacts representing the ongoing codification of producer-user interactions around technologies. At the same time, technical artifacts and associated knowledge and routines shape these interpretive frames in a co-evolutionary manner. This more complex model of interpretive systems and technical change is illustrated in Figure 2.

-- Insert Figure 2 here --

We categorize ongoing producer-user interactions along two dimensions (see Table 2). First, we consider the level of intentionality: whether the interaction is passive or purposeful. Within the managerial cognition literature, interactions are often characterized as passive, with the actors portrayed as almost victims of their frames. Passive interactions among actors involve data gathering and interpretation, with no intent to modify the behavior or understanding of other organizations or individuals. At the opposite extreme, we propose that interactions can be more self-conscious and strategic. These more purposeful actions are taken with the intent of shaping the perceptions and actions of other actors to create an advantage.

Second, we consider the level of intensity: whether the interaction is loosely coupled or tightly coupled. Loosely coupled interactions involve minimal direct communication and often occur indirectly through third parties such as complementary producers. More tightly coupled interactions involve deep integration of producer and user innovative activities. In this case, the learning processes of producers and users are combined as they engage in joint problem-solving and experimentation.

-- Insert Table 2 here --

Passive-loosely coupled interactions. Passive-loosely coupled interactions are often simply decentralized market exchanges. Producers offer a set of products on the market, and consumers either purchase them or don't, depending upon the price and quality. Producers then infer consumer preferences based upon observed behavior. Traditional survey-based market research (e.g., Urban and Hauser 1993) provides another example of this type of interaction. The goal of even the highly sophisticated tools is to capture user preferences, not shape them. Although not mindful, these interactions still influence the frames held by producers and users.

Passive-tightly coupled interactions. Passive, but more intense, interactions involve market research methods such as lead user studies or rapid prototyping (von Hippel 1986). Although testing products through the use of prototypes is a common way to elicit product feedback, rapid prototyping involves a fundamentally different level of commitment and interaction, with design alternatives and feedback moving back and forth across the producer-user boundary in quick succession. When the actors engage in such tightly-coupled interactions, all aspects of their interpretive systems become interwoven. Scanning and noticing, interpreting and acting all become joint activities with shared sensemaking, leading to coherence in the emergent beliefs around the new technology.

Purposeful-tightly coupled interactions. Intense interactions can also be strategic, when one or both of the involved parties is actively attempting to influence the perceptions of the other. Formal relationships such as strategic alliances for the development of a new product would enable purposeful interactions. Some forms of joint experimentation with users could also fall into this category. While data on the effectiveness of this type of interaction is still limited, in their study of the evolution of wind turbines in the US vs. Denmark, Garud & Karnoe (2003), found that Danish firms, which used a "bricolage" process of joint experimentation with incremental technologies, were much more successful than US firms, which had limited interaction with users and were instead focused on finding breakthrough technologies.

Purposeful-loosely coupled interactions. In contrast to this intense interaction, other purposeful forms of producer-user interaction are indirect, involving little one-on-one communication. Given the high uncertainty surrounding new technology, advertising and press coverage help users to make sense of the technology, including what product analogies to draw, how to use new products, or what features to value (Rogers 1995). Firms also engage the media in "technological dramas" in order to influence the perceptions of a range of actors regarding a new technology (Lampel 2001). These dramas often take the form of theatrical product announcements or demonstrations, such as Edison's announcement of his illumination system (David 1992) or the speed typing contests that drew attention to the QWERTY keyboard design (David 1986). They help to shape the frames of important constituents regarding the new technology.

Producers, in particular, can have an influential role in communicating to users how to make sense of new technology. For example, IBM in the 1980's reinforced its dominant position in mainframes by controlling its "strategic projections" very tightly. These messages to the outside world influenced industry-wide categorizations of industry structure and reinforced IBM's competitive advantage (Rindova and Fombrun 1999). In an era of ferment, producers can influence which product characteristics consumers value (Das and Das 2001; Tushman and Rosenkopf 1992). Producers who enter a market first have the potential to establish a "pioneering advantage" in that they can shape user preferences, defining the criteria upon which to evaluate new products in a manner that benefits them (Carpenter and Nakamoto 1990). Producers can also attempt to influence the evolution of new product categories to their advantage. In their study of the evolution of minivan categories, Rosa et al (Rosa, Porac, Spanjol, and Saxon 1999) show that once a category label stabilized (through a consensus among producers and users) minivan models that fit within that label had greater market acceptance, even with no material changes to the models.

Producers also influence users' frames indirectly through interactions with complementary producers. In battles between competing technologies characterized by increasing returns to scale, user expectations about the future of each technology are crucial in determining which direction the market will tip (Arthur 1988). The actions of complementary producers have a profound influence on user expectations (Afuah 2000; Gawer and Cusumano 2002), and by influencing those actions, producers indirectly influence user interpretations. In addition, through interactions with institutional players, producers can influence others' frames about a technology. Rosenkopf & Tushman (1998) show the importance of technical communities, such as standards bodies, in shaping the understanding of flight simulation technology. Institutional endorsements also confer legitimacy upon new technologies, product markets, and firms participating in those markets (Baum and Oliver 1991; Rao 1994).

We take notions of institutional importance one step further and argue that institutions also influence cognition. Both producers and users look to a variety of institutions for signals when engaging in the interpretive system of noticing, interpreting, and acting upon the information environment. This can often operate in a reinforcing cycle between micro-level individual cognition and institutionalization of shared cognition at the macro level (van de Ven and Garud 1994). In the case of the cellular service provider and equipment industry, for example, joint participation by managers in technical committees was a medium for exchange of knowledge and, therefore, improved their ability to identify alliance opportunities (Rosenkopf, Metiu, and George 2001).

An illustration: the evolution of the Personal Digital Assistant (PDA)

We use the case of PDAs (Personal Digital Assistants) to illustrate the dynamics of the interactions between different interpretive systems in shaping the evolution of a technology.

While previous studies of this industry have examined standard-setting strategies (McGahan, Vadasz, and Yoffie 1997), alliance formation (Gomes-Casseres and Leonard-Barton 1997), and product entry timing (Bayus, Jain, and Rao 1997), we believe that a deeper understanding of the industry's evolution emerges when one examines the role of cognition. In each of three important stages of PDA development – its initial emergence, the movement towards a dominant design, and recent trends towards merging with related technologies such as mobile phones – the interpretations made by producers and users have interacted to shape the technical trajectory.

Three eras

Emergence of the PDA. While John Sculley, former CEO of Apple, was the first to use the term "personal digital assistant," or PDA, in 1992 and industry analysts such as IDC only recognized the PDA as a product category in 1996, the precursors of the PDA extend more than a decade earlier to products such as the Iasis Computer-in-a-Book launched in 1976, the Hewlett Packard 75 launched in 1982, and a host of tiny notebooks or laptop portables such as the GRiD Compass 1100 (1982) or the NEC PC-8000 (1983). The core technologies embedded in each of these products was remarkably similar. The form factors (physical design) and features emphasized by each, however differed, reflecting the background of producer firms. HP's product bore a striking resemblance to a calculator, NEC's to a word processor, and the Iasis and Grid products to computers. Thus, despite similar technical capabilities, we see framing resulting in quite different artifacts (see Figure 3).

-- Insert Figure 3 here --

By the late 1980's and early 1990's, the category of PDA was starting to emerge, but there was still significant technical and cognitive variation. Once again, although firms had access to similar technology (Bayus, Jain, and Rao 1997), their codification of that technology in the form of product artifacts differed significantly. Products could be characterized along a number of dimensions, including: wireless communications capability, PC connectivity, applications (e.g. organizer, spreadsheet, word processor), and pen-based vs. keyboard centric. Table 3 contrasts some of the broad range of products announced during this era. In addition to a range of features, there was also a range of form factors (Figure 4). Pen-based products such as the GriDPad and Apple's Newton focused on contact and calendar functions. Others such as the Atari Portfolio had keyboard-based input and were positioned as PC-substitutes. Yet other products, such as the Sony Magic Link and the Motorola Envoy, had pen-based input, but were positioned as communications devices, with PC-type applications including spreadsheet, and word processing programs.

-- Insert Figure 4 and Table 3 here --

Although the Apple Newton was the most notable of the failures in this group, with estimates of Apple's losses running up to $50 million, these products were all unsuccessful and soon withdrawn from the market. The PDA category lost credibility amongst investors, analysts, and consumers: Donna Dubinsky, Palm founder, noted, "After those dismal holiday sales [in December 1993] the [PDA] category got very cold. It didn't matter that we were one of the cleverest companies in the category . . . the world felt we were in a dog category."[4]

In early 1996, the first successful PDA – the Palm Pilot – shipped. The success grew partly from improved technology (in particular, Graffiti handwriting recognition). But, the main source of success was a critical insight about use: while many previous PDAs had been

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[4] Dodson, S & Hart, M. "Palm Computing, Inc. 1995: Financing Challenges, HBS Case #9-898-090, HBS Publishing, 1998, p.5

positioned as PC replacements, attempting to replicate much of the PCs functionality, the Palm Pilot was to be a companion to the user's PC, with connectivity the crucial function. As Palm founder, Jeff Hawkins commented, "We set as our goal a $299, shirt-pocket-size [product], focused on connectivity [to a PC] as the fundamental functionality."[5] This shift decreased the need for processing power and memory, thus relieving constraints and enabling a simpler design and feature set.

Move toward dominant design. Palm began licensing its operating system (OS) in 1997 and competition sprung up quite quickly. Palm reacted with a string of new product launches focused mainly on improvements in memory, screen quality, connectivity and design. In an attempt to build critical mass for the Palm operating system, the firm actively cultivated its developer community, growing from nearly 3,600 developers in 1998 to more than 260,000 in January of 2003. These developers produced many applications that allowed users to customize the device to their use, adding such features as games, electronic books, expense account tracking, medical patient tracking, wine collectors catalogue, medical reference for doctors doing rounds, the New York subway map, a calorie counter, a tip calculator for restaurant bills, truck fleet tracking, and on and on. Understanding what applications were being developed helped Palm know what the users ultimately wanted in a hand held device. Thus, both producers and users, as well as the developer intermediaries adjudicated the dominant design.

Strong competition emerged, including from Palm OS licensee, Handspring, a company launched by the founders of Palm (Hawkins and Dubinsky) who left Palm after it was acquired

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[5] Dodson, S & Hart, M. "Palm Computing, Inc. 1995: Financing Challenges, HBS Case #9-898-090, HBS Publishing, 1998, p.8.

by 3Com.[6] The first Handspring product, the Visor, was shipped in late 1999, and took expandability to another level by offering a "Springboard" expansion slot that enabled a tremendous range of add-on applications and features. While initial competition for Palm came from other players licensing the Palm OS, in the late 1990's devices using the Microsoft Windows CE operating system began to take hold and by 1998 Compaq (iPaq), Hewlett Packard (Jornada), LG Electronics, Philips, and Sharp, as well as a number of smaller players, had all launched Windows CE devices.

Although the Windows CE operating system was not initially very successful, subsequent incarnations encountered much greater fortune. In particular, Microsoft shifted its strategy by rebranding the CE operating system "Pocket PC" and announcing the shift with much fanfare at New York's Grand Central Station in April 2000. By labeling PDA devices "Pocket PCs" Microsoft was clearly attempting to influence consumer's perceptions of what functions a PDA should offer. In a not so subtle way, Microsoft was fighting Palm and telling users that they should expect to find PC functionality on a PDA.

Over time, differences between Palm and Pocket PC devices melted away (see Figure 5). While CE devices originally had keyboard input they migrated to a system of pen-based input. Similarly poor CE battery performance was improved to match the Palm. Palm devices originally couldn't handle Microsoft Office documents, but a license from DataViz technologies brought Office documents to Palms. There was also an emerging consensus around the Palm-style form factor: pen-based input, 3-4 inch long screen, 4 buttons at the bottom for commonly used applications, and some form of connectivity to a PC.

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[6] Their product, the Visor, used the Palm OS. While Palm dismissed Handspring as a rival (because it was paying $8 per unit for the OS license), the Visor gained a 15% market share after only 15 months in the market.

-- Insert Figure 5 here --

Through 2000, the PDA market was characterized by steady improvements in memory, screen quality (including the addition of color), weight and size, and price/performance. Day-to-day competition was enacted through a search for special features; firms pushed different boundaries of usage to determine what end users would be willing to do with a PDA. For example, Sony launched a version of their Palm OS-based Clié which doubled as a universal remote to control the television, VCR, stereo and even the lighting system in a house.

Reopening: a new era of ferment. In 1999, the Canadian company Research in Motion launched the Blackberry device, which, in addition to providing Palm-type functionality, added a wireless streaming email capability with a thumb-based keyboard for typing. By 2001, product sales of the Blackberry grew at 59% vs. Palm's 2.5% decline. In a way, this event marked the beginning of a new era of ferment period for PDAs. By late 2003, a number of previously distinct product categories, including PDAs, cell phones, wireless data communicators, and digital cameras were beginning to merge.

The origins of combined functionality devices were to be found in previous activities by both producers and users during the era of the Palm-based dominant design. Independent developers saw expansion slots such as that in the Handspring as an opportunity to offer functions such as email and wireless data communications on a PDA. In addition, on the producer side, cell phone manufacturers had slowly been encroaching on PDA space with a Nokia cell phone/PDA launched in 1997 and a Qualcomm product based on the Palm OS in 1999. By 2001, many of the price and size issues of these early products had been at least partially resolved, and Kyocera Wireless and Samsung both launched second generation versions also based on the Palm OS. These devices and those launched over the subsequent few years had a of “clam shell” form factor,[7] but emphasized the primacy of voice rather than data in their interfaces.

As of 2003, three evolving form factors with similar overall capabilities, but different emphases, competed for space: the traditional Palm or CE device style with a focus on organizer functions, the Blackberry style with a small keyboard and a focus on “always-on” data communication functions, and the cellular phone style that emphasizes voice communications over other features. In addition, cell phone/PDA/digital camera combinations were becoming popular.

-- Insert Figure 6 here --

Figure 6 shows some of the alternatives in this new era of ferment. There is disagreement about how this competition among devices will get resolved, with analysts such as Kevin Burden at IDC arguing “this is a multiple-device world . . . . Don't expect there will ever be one killer device,”[8] and others such as Jeff Hawkins (currently of Handspring) commenting, “Do people want to carry around a single device for voice and data communications? The answer is absolutely yes. People would rather have a single device, but they won't put up with major compromises on the device.”[9] As of this writing (2003), the answer is not yet clear.

PDAs in the interactive interpretive system model

We began the exposition of our model by proposing that prior experience drives the formation of frames through which producers and users filter the environment. The importance

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[7] “Clam shell” designs differed from the dominant Palm-style form factor in that they had two parts (a lid and keyboard) which were hinged and closed on each other when the device was not in use.
[8] “All in One,” Piu-Wing Tam, Wall Street Journal, May 19, 2003.
[9] “What's Ahead for...Mobile Computing: The creator of the Palm Pilot talks about the future of handheld computers,” Pui-Wing Tam, Wall Street Journal, June 25, 2001.

of history in the formation of frames, and subsequent action, is evident throughout the evolution of the PDA industry. Predecessors to the PDA were very much descendants of the existing product lines and mindsets of the firms moving into the new technological arena. Hewlett Packard's vision of what a PDA might be was driven by experience in the calculator business, and similarly, NEC viewed a PDA as a PC-substitute. Additionally, in the most recent era of ferment it was clear that firms with different histories interpreted user needs differently: cellular handset companies tended to believe that voice was the primary function while companies with a history of PDA development were more likely to feature data. Reviews in 2003 of the Kyocera 7135, a phone/PDA product made by a cell phone firm highlighted the ongoing bifurcation of the market.

> *" In the 7135, Kyocera has remained true to its conviction that combo products should be phones, first and foremost, in contrast with many competitors… If you don't care about e-mail, the 7135 is a decent combination of a phone and a Palm PDA."*[10]

Consistent with what we would anticipate in our model, we observed both technical and cognitive variation in the early years of the industry. Even as some of the technical variation was resolved, cognitive variation remained. Early entrants into the industry, such as Apple and Motorola, had access to similar technologies but chose to commercialize that technology in quite different ways: the Newton was organizer-focused; the Envoy was communications-focused. Over time, through the interaction of both producer and user interpretive systems, this variation decreased and the industry settled on a dominant design in the image of the Palm Pilot, which concentrated on PC connectivity and organizer functions.

Once the Palm emerged as dominant, most producers then fell in line with the basic interpretation of the technology form factor and functions. In the early stages, this shared

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[10] "Kyocera 7135 Packs In Features -- and the Bulk," Walter Mossberg, Wall Street Journal, April 17, 2003.

interpretation helped establish the legitimacy of the category in the eyes of the financial and consumer markets. For instance, after the introduction of the Palm Pilot in 1986, industry analyst IDC finally recognized PDAs as a product category. Thus, an important part of the dominant design was closure on framing, and not just on choice of technology.

The emergence of a new era of ferment in PDAs resulted from a combination of new technology and ongoing sensemaking on the part of users. The Blackberry, with a focus on email and messaging, represented a new interpretation of what a PDA could be, and new dimensions of merit became relevant. While the Blackberry certainly brought new technology to the PDA industry, hints of the Blackberry functionality were to be found in the innovations made by user developers within the Palm Pilot community. For instance, an email application, which allowed users to compose emails on the Palm and have them sent whenever the Palm was "hot synced" indicated that users were continuing to see the potential of new functions, even within the constraints of the existing dominant design. This ongoing sensemaking is consistent with Orlikowski's (2000) observation that adopters of Lotus Notes continued to re-interpret its use and meaning even after the initial period of integration.

Throughout the evolution of the industry we also see strong evidence of purposeful interactions among producers and users, with producer firms in particular attempting to influence the sensemaking process of users. Microsoft's use of the term "Pocket PC" combined with its theatrical announcement of the Pocket PC OS at an event in Grand Central Station, provide an example of purposeful but loosely-coupled interactions. Other loosely-coupled interactions took place through intermediaries such as industry analysts, institutions, and complementary producers. As Donna Dubinsky noted when outlining Handspring's approach to partnerships, “We may get people to partner with us to execute pieces of our vision, but we’re going to make it very clear that it’s our vision and our direction”[11]

The application developers, who were actively cultivated by Palm in particular, served in the emergence period to generate demand for the devices by making them easier to use and also providing functions that appealed to customers. The applications that they developed were based on their own interpretations of what a PDA should do; in fact, the developers were most often also users of the technology and identified themselves as such.[12] The artifacts produced by the developers (applications and hardware additions such as cameras or MP3 players) became market input for the producers that allowed them to understand what the PDA was and could be used for. As the dominant design emerged, these features were often incorporated by the producers into the standard product itself; however, the initial insights often emerged from user/developer innovation as they interpreted the PDA technology. During the more recent era of merging technologies, a third set of intermediaries has come to the fore, the wireless service providers. The combination of PDAs and cell phones into a single device was initially driven by the device manufacturers (either on the PDA or the mobile phone side), but the service providers’ (such as Verizon, Sprint PCS, etc.) interpretations of this new technology and the potential features that could be offered is influencing how the devices are evolving – some providers are pushing for devices that offer primacy to voice, others for ones that favor data. While it is too early to tell what the outcome will be, the device manufacturers are working closely with these intermediaries to understand their interpretations and incorporate those views into the design of new devices.

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[11] Feldstein, J., C. Flanagan, & C. Holloway, “Handspring – ‘Partnerships’” Stanford GSB, Case #SM-79, 2001, p.5.
[12] In their postings on the Palm web site for users, participants often made claims such as “I have been an avid Palm Developer and Palm User for the past three years…”, (http://www.palmsource.com/community/user_groups.html).

Discussion and conclusion

In this paper we set out to explore the relationship between cognition and technological evolution, developing a model of how the interpretive systems of producers and users interact in the evolution of a new technology. While the field of managerial cognition has recently received increasing attention, cognitive perspectives have, with a few notable exceptions, yet to gain a significant foothold in the management of technology field. We believe that given the high levels of uncertainty surrounding a new technology, cognitive framing plays a major role in determining how the technology and associated markets unfold. In the context of a new technology, producers and users must make sense of a confusing and complex information environment. Based upon their divergent frames, they make judgments about a number of issues including whether and how the technology will work, which of multiple paths it might take, how it will be used, and what users will value. A cognitive lens thus has a great deal to contribute to our understanding of technological evolution. We illustrate the value of the model through an analysis of the ongoing evolution of Personal Digital Assistants (PDAs).

In our model, the disparate histories of multiple actors result in divergent frames, and therefore, different interpretations of new technology. We see these differences clearly illustrated in the evolution of PDAs. For instance, original entrants to the industry came from the computer industry, and that background resulted in an interpretation of a PDA as a computer substitute. Thus, while much of the management of technology literature has focused on the importance of competencies when developing new technology (e.g., Tushman and Anderson 1986), our model would lead us to believe that framing is equally important. One should consider not only whether new technology requires radically new capabilities, but whether it also requires new frames.

The PDA story also demonstrates the importance of interactions among interpretive systems. In attempting to recruit third-party developers to work on a particular PDA platform, a shared belief in PDAs as a legitimate product category was a necessary precursor. Even when the category was established, the preferences of users – how they were using the technology and what applications they valued – were being communicated to producers indirectly through the results of third-party developers. While the importance of encouraging complementary producers has long been recognized in technology battles (e.g., Arthur 1988; Gawer and Cusumano 2002), our model highlights the role of their interpretive systems. In addition to providing such developers with economic incentives to support a given technology platform, shaping the developers' beliefs about how the technology gets used can be an equally important lever. The frames of users, complementors, and producers were thus intimately intertwined. We can thereby conceive of processes of variation, selection, and retention as applying not just to technologies, but also to the frames. Competing technologies and competing frames are both resolved through interactions among interpretive systems.

This model also sheds new insight on the phenomenon of user innovation. While theory on the economic incentives for user innovation is well developed (von Hippel 1986), this paper suggests a complementary perspective. In addition to innovating when they have strong economic incentives, users may also innovate when their frame of a new technology differs significantly from that of producers. In these situations, users may be in the best position to develop products that are consistent with their vision of how the technology should develop. So for instance, in the evolution of PDAs, a number of the complementary application developers were also users. In addition to having an economic incentive to innovate, one could argue that these users had very different frames, enabling them to innovate in a manner different from what producers might have done.

Although researchers have already suggested research agendas related to managerial cognition in a broad context (Huff 1997; Meindl, Stubbart, and Porac 1994; Walsh 1995), issues remain to be uncovered when it comes to understanding the dynamics of technical change. The development of this model and the illustrative example of the evolution of PDAs suggest a research agenda that could further examine the interrelationships between the interpretive systems of producers and users that we portray in the model, expand our understanding of the nature of cognition itself, and more closely link research methods with the nature of the problem at hand.

While there is empirical evidence, if limited in some cases, for each of the separate effects in the model, there is little work that takes into account the linkages across the interpretive systems of producers and user. If we understand technical change to involve interactions between the technological artifact and the interpretive systems of the producer and the user, we raise a whole host of new research questions: What determines which frames will be salient at any one time? What forces determine which frame "wins" over time, if indeed there is a winner? When are these interactions tightly or loosely coupled? How do producers or users move from one set of frames to another? To what extent can producers and users shape the others' frames? And, what are the constraints on this more mindful, strategic process?

We also suggest that the notion of a system with interactions will force us to expand our concept of cognition. In this interlinked set of interpretive systems, we suggest that cognition is not just about "frames" but rather as a situated process of "framing" that is the product of interactions among people (Hutchins 1995; Lave 1988; Lave and Wenger 1991; Tyre and

Orlikowski 1994). This view is in contrast to the purely cognitivist approach in which knowledge is a context-free, "factual" construct and bounded rationality is only about the technical limits of the mind (Simon 1947). In the context of emerging technologies, it is therefore relevant to examine the relationship of both the "framing" process of developing and using frames and the content and structure of the "frames" themselves to outcomes in eras of ferment. Could we think of cognition in the way that Swidler (1986) talks about culture, as a repertoire (or "toolkit") of views that get activated depending on context and interaction? Can we be more effective in studying "cognition in the wild" to see how cognition emerges in practice (Hutchins 1995; Lave 1988; Orlikowski and Gash 1994)?

The model also suggests that researchers in this area may have to rethink methodological approaches. Approaches that are both longitudinal and cross sectional (at least paired comparisons) will be most likely to shed light on cognition in eras of ferment. Because the era of ferment is continually evolving, snapshot maps of a specific moment in time will not be effective in understanding the role that cognition plays in the ultimate outcomes (Oliver and Johnston 2000). A longitudinal approach demonstrating how frames change through the era of ferment will be essential. This type of analysis could be aimed at understanding how frames are formed (antecedent conditions such as experience and routines) and how they evolve over time. Influences on evolution could include perception of new information and emotional reaction to new information or group dynamics within organizations.

The most problematic aspect of studying cognitive frames is the risk of retrospective reconstruction. The uncertainty during eras of ferment and the fact that clarity about the nature of the discontinuity is only reached after the fact, means that *ex post* efficiency explanations are inappropriate. This concern has two methodological implications: the need to present a "symmetric account of different paths irrespective of whether or not they were eventually successful" (Garud and Rappa 1994) and the importance of using contemporary data sources. These requirements, coupled with the desirability of a longitudinal approach, put stringent demands on the researcher. Answering the kinds of questions posed by cognition and technical change may also lie in understanding the microprocesses of real-time decision making, the real day-to-day perspectives and events that shape outcomes. It is in the microprocesses that one can observe the way in which the framing of the industry context and of the nature of the technological change can affect choices.

In conclusion, the emerging importance of the managerial cognition field gives us an opportunity to revisit a number of important questions in the stream of research on technical change. First and foremost, our model emphasizes the need to consider the interlinked nature of the phenomena. This would suggest that it is risky, for example, to examine how producing firms react to technical changes without acknowledging that their reactions also shape the very nature of the change itself or that user interpretations of the technology might move it in directions entirely unanticipated by the producer. Thus, harkening back to the vociferous debate about the relative merits of demand-pull or technology-push theories (Mowery and Rosenberg 1982), we suggest that both market pull and technology push have independent roles in technology evolution but also that this occurs through the interaction of the producer (push) and user (pull) interpretive systems.

These explanations come at the cost of increasing complexity. We built this model from the foundations of Daft and Weick's relatively simple and elegant contribution. Yet, even they noted that interpretive systems are "awesomely complex" (Daft and Weick 1984: 294) and that precision and accuracy might lose sight of the phenomenon. In order to map out the role of cognition in technical change, we have introduced more layers into the model, layers which make the theoretical and methodological challenges to research messier rather than simpler. Because we are at the early stages of understanding these issues, we think the messiness is both necessary and appealing.

The model may also have power on the normative front. If we can understand how interpretive systems work in relation to technical change, there is potential, for example, for the strategic manipulation of user cognition to improve adoption. How can firms actively manage the manner in which customers make sense of new technologies in order to optimize their own positions? Similarly, how can firms be more effective at managing cognitive change? How can they actively manage shifts in cognitive frames in the same manner they manage shifts in capabilities? Does it make sense to hire people with different framing in order to promote innovation? Are there implications for team demography? We believe that further empirical research into how producers and users think about technology can bring greater theoretical and managerial insight.

Figure 1: The organization as an interpretive system

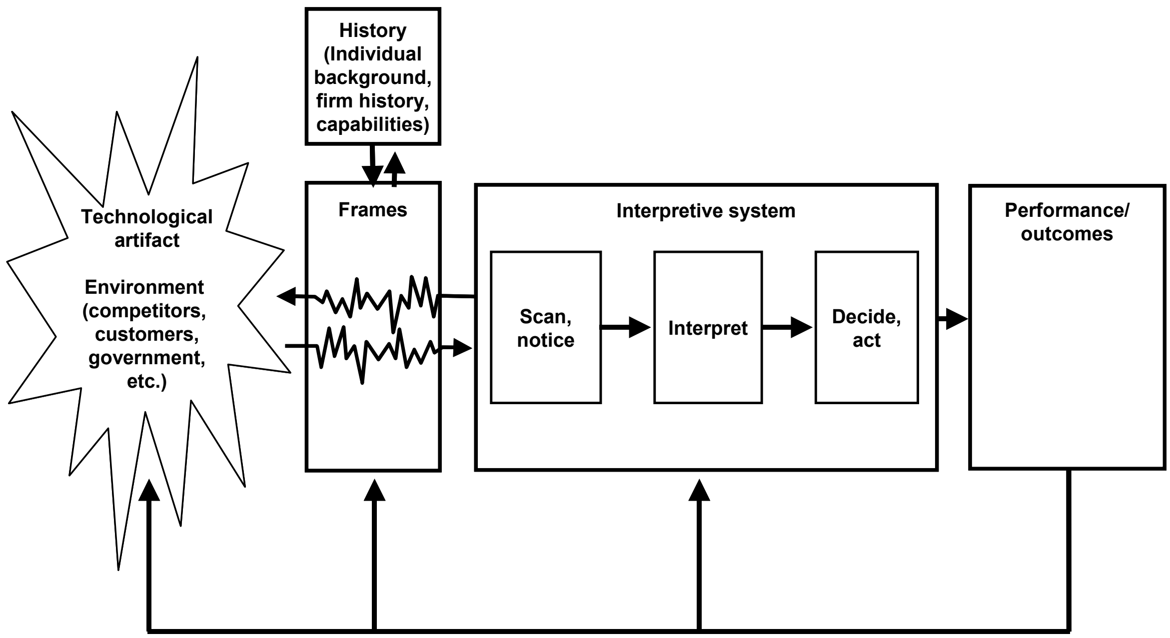


Figure 2: Co-evolutionary model of interaction of producer and user interpretive systems

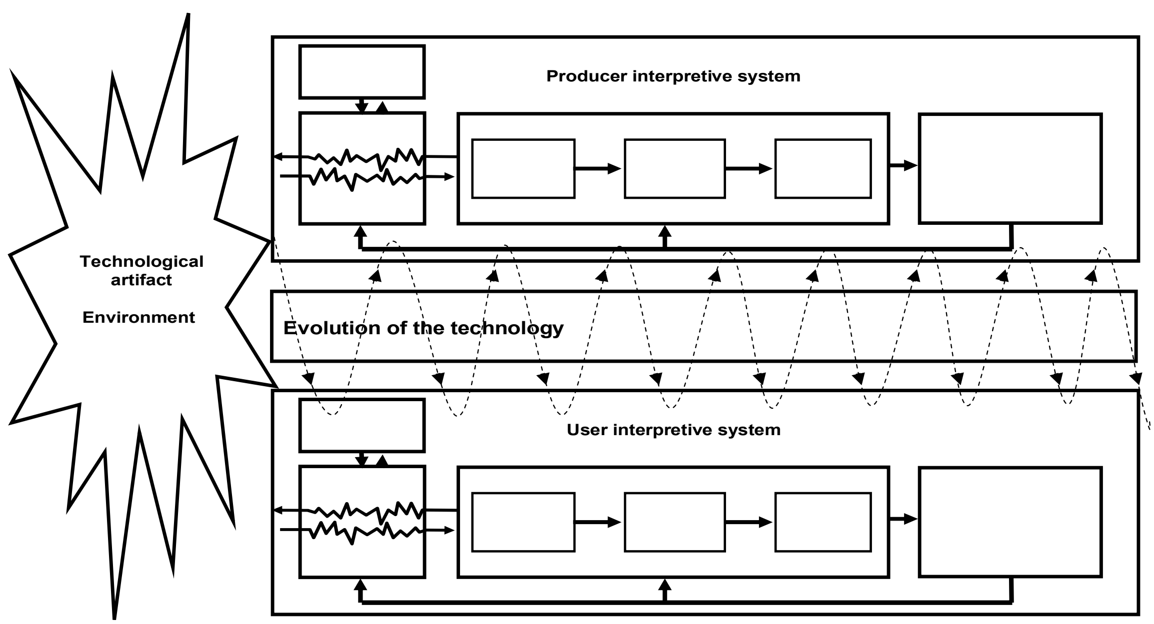
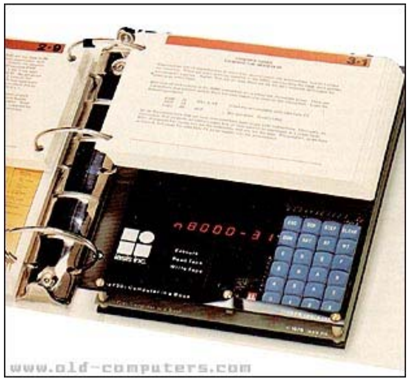


Figure 3: Precursors to the PDA

Iasis Computer-in-a-Book (1976)



GRiD Compass 1100 (1982)

Hewlett Packard 75c (1982)

NEC PC-8000 (1983)

Figure 4: Early PDAs

GRiDPad (1990)

Apple Newton

Atari Portfolio (1989)

Sony Magic Link

Figure 5: Temporary dominant design

Palm Pilot 1997

Compaq iPaq (Windows CE) (2002)

Sony Clie (Palm OS) (2002)

Figure 6: The new era of ferment: merging of technologies

Research in Motion Blackberry (1999)

Kyocera 7135 (2003)

Palm Tungsten (2003)

Sharp Zaurus (2003)

Table 1: Producer and user frames about the technology, the environment and themselves

Frames about the technology (by both producer and users)	Frames about the environment (by both producer and users)	Producer frames about themselves in relation to the technology	User frames about themselves in relation to the technology
• What is the performance trajectory of the technology? How quickly and how much will its performance improve? When will it reach its limits? • What will the technology cost over time? • If there are competing technologies, which will win? • What uses will the technology have? • How large is the market for the technology? Which customers will value it? • What dimensions of merit will users value? What is core and what is peripheral?	• How will regulations affect the evolution of the technology? • What firms will be in the relevant competitive set? • How will firms producing complementary products act? • What actions will other relevant institutions, such as standards bodies, take?	• What are the firm's capabilities in relation to the technology? • Is it a competence destroying or competence enhancing technology? • Is the technology a threat or an opportunity? • What business model should the firm use to commercialize the technology? Should we establish a new division to pursue the technology? • What customers will be relevant? • Does a particular new entrant pose a credible threat?	• How will the technology affect the way my organization operates? • What criteria should we use to evaluate the technology? • Can or should this technology replace something I do now? What might it enable me to do differently? • What skills will be required to take advantage of this technology? • Is it worth making the required changes to adopt the technology?

Table 2: A Typology of Producer-User Interactions with examples

	Intentionality of interaction	
Intensity of interaction	***Passive***	***Purposeful***
Tightly coupled	Lead user market research Beta testing Rapid prototyping/joint experimentation	Strategic alliances
Loosely coupled	Survey-based market research Decentralized market exchange	Advertising campaigns Public relations Indirect interactions with intermediary actors (e.g., complementors)

Table 3: Features of early PDAs

	Atari Portfolio	**Grid Pad**	**Apple / Sharp Newton**	**Tandy/ Casio/Palm Zoomer**	**Sony Magic Link**	**Motorola Envoy**
Announcement date	Fall 1989	Fall 1989	Spring 1992	Summer 1993	Spring 1994	Spring 1994
Form factor						
Input	Keyboard	Pen-based	Pen-based	Pen-based	Stylus keyboard	Stylus keyboard
Weight	15 oz.	5 lbs.	15 oz.	16 oz.	1.2 lbs.	1.7 lbs.
Battery life	65 hours	8 hours	14 hours	90 hours	10 hours	8 hours
Functions						
Communications:						
Infrared	No	No	Yes	Yes	Yes	Yes
Fax modem	No	No	Option	Option	Yes	Yes
Applications:						
Organizer	Yes	Yes	Yes	Yes	Yes	Yes
Spreadsheet/ word processor	Yes	Yes	No	No	Yes	Yes

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