The Tables Have Turned:
How can the Information Systems field contribute to technology and innovation management research?

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Introduction

In the second half of the last century, modularity emerged as a powerful idea for dealing with increasingly complex systems (Schilling 2000; Simon 1962). Noting the transformative power of this perspective, Baldwin and Clark (1997) declared the arrival of the “age of modularity.” They argue that modularity was at the heart of the remarkable rate of innovation in recent history, since modularity enables firms to design and build a complex product and process from smaller subsystems and components. Although modularity is often associated with a product architecture (Ulrich 1995), it has broad implications on how firms should be organized in designing and producing complex products and processes (Sosa et al. 2004). Indeed, modularity has provided an intellectual bedrock of organizational scholarship that has produced a significant body of work in the domain of innovation and technology management (Garud et al. 2003; Schilling 2000).

The information systems (“IS”) community has primarily played the role of a recipient of the theory of modularity. Much of IS research over the last three decades has been influenced -- explicitly or implicitly -- by modularity and its consequences in organizations. Modularity has provided an important context for some of the key topics that IS scholars have studied in the past. Given the pervasive digitalization that we see in society (Lyytinen and Yoo 2002), however, the logic of modularity can no longer provide a sufficient theoretical framework to explain contemporary economic phenomena. Products and services that are enabled by programmable digital technology and are connected to the Internet a unleashing a new wave of generative innovations (Yoo et al. 2010). Generativity refers to an “overall capacity to produce unprompted change driven by large, varied, and uncoordinated audiences” (Zittrain 2006). Such innovations are distinctly different from previous innovations that are rooted in the precepts of modularity (Tilson et al. 2010; Yoo et al. 2012; Yoo et al. 2010). Going forward, management scholars need to account for the changes brought by digitalization, and build new theoretical frameworks to guide efforts to organize for generative innovations. In this essay, I argue that the IS community can lead such an effort by drawing on its intellectual tradition of sociomateriality. Below, after describing the shift from modularity to generativity, I will propose how IS scholars might work toward a sociomaterial theory of organizing for generativity.

The Age of Modularity

Modularity is a general systems concept. It provides “design rules” that define how a system is divided into subsystems and how those subsystems are interconnected (Baldwin and Clark 2000; Schilling 2000). Modularity offers simplicity in dealing with a complex system. One can focus on an overall system -- whether it is a product or process -- while leaving the detail design of subsystems and components to others. Modularity allows for an effective division of labor among different actors during design and production (Sosa et al. 2004; Staudenmayer et al. 2005). Not only does modularity reduce complexity, it also increases flexibility by allowing “mixing-and-matching” (Garud and Kumaraswamy 1995; Sanchez and Mahoney 1996). Such a mixing-and-matching" strategy is possible as one can replace one component with another as long as they both confirm to the same standardized interface. Baldwin and Clark (2000) note that modularity can provide real options to manufacturers as it allows rapid customization and multiple evolutionary trajectories.

Scholars have also noted that modularity influences the evolution of products and product life cycles (Abernathy and Utterback 1978; Clark 1985). For example, Garud et al. (2003) note that modularity provides the necessary stability for a system in an evolutionary environment, and "enhances the speed, scope and reach of innovation" through improved retention and reuse of components. Tushman and Murmann (1998) also note that the emergence of a dominant design is associated with the establishment of standardized interfaces among subsystems and components that are enabled by modularity. Dominant designs are turning points for an industry; custom-made products evolve into standardized products that can take advantage of advanced manufacturing systems (Abernathy and Utterback 1978). As a result, dominant designs lead to a rapid expansion of market and price/performance improvements (Anderson and Tushman 1990).

Not only does modularity affect product evolution, but it also affects the way firms are organized (Sanchez and Mahoney 1996; Schilling 2000). As standardized interfaces and hidden design parameters encapsulated within modules lower transactions costs, firms can effectively pursue external network effects by leveraging specialized component producers (Langlois 1992; Shapiro and Varian 1999). As a result, traditional hierarchical, vertically integrated firms become disintegrated and firms increasingly rely on the external network of specialized firms (Baldwin and Clark 2000; Langlois 1992). Langlois and Robertson (1992) demonstrate how the modular architecture has brought vertical disintegration to the computer industry and the emergence of specialized components developers. Similar effects of modularity on organizational structure have been observed in the software (Chandler and Cortada 2000) and telecommunication industries (Tuomi 2002). Together with the advent of the Internet, which radically reduced communication and coordination costs (Brynjolfsson et al. 1994; Malone et al. 1987), modularity has disaggregated “the traditional value chain into value networks” (Garud et al. 2003; Sosa et al. 2007). Thus, modularity has enabled not only economies of scale, but also of scope and substitution (Garud and Kumaraswamy 1995). Firms like Cisco, Dell, and Nokia invested heavily in corporate IT infrastructures to realize “net-enabled” value networks (Sambamurthy and Zmud 2000; Wheeler 2003) whereby design and production activities could be radically distributed among networks of specialized firms (Nohria and Eccles 1992). As a result, the key source of value creation has become the agility that flows from the ability to rapidly re-combine components within a product architecture without sacrificing cost or quality (Eisenhardt and Martin 2000; Sambamurthy et al. 2003).

A large body of IS research over the last three decades has been carried out in this precise historical context of organizational shifts from vertically integrated hierarchies to networks of distributed, specialized firms, teams and individuals (Fulk and DeSanctis 1995; Sambamurthy and Zmud 2000; Zammuto et al. 2007). Such topics as process-centric organizational designs, virtual teams, supply chain management and knowledge management all deal with, in part, different aspects of challenges that modularity has brought to firms. A process-centric view of organizations and the role of IT in it (Davenport 1993; Overby et al. 2010), for example, stems from the modularization of processes. Virtual teams became an important issue for IS scholars in part because firms increasingly deal with individuals and teams with specialized skills who are distributed globally (Jarvenpaa and Leidner 1999). Similarly, supply chain management and off-shoring directly deal with the consequences of modularity that moves firms from hierarchical values chain to value networks (Leonardi and Bailey 2008; Levina and Ross 2003; Malhotra et al. 2005). Finally, as modularity promotes reusability of the same capability through the principle of mixing and matching, knowledge sharing and reuse across different contexts become an important challenge that IS scholars have embraced (Alavi and Leidner 1999). In this sense, the research agenda of the IS community over the last three decades has been, to a degree, shaped by the modularity discourse that began with technology and innovation management scholars.

Over time, however, IS scholars have built a unique and robust intellectual perspective as they have examined the role of IS in increasingly modular organizations. This tradition suggests that a dynamic and mutually reinforcing interplay between social and technical elements *jointly* determines organizational outcomes (Leonardi 2011; Orlikowski and Scott 2008). In research in the area of software design, task-technology fit, group support systems, and technology acceptance model, the socio-technical perspective has been at the core of the IS discipline. Although coming from a very different intellectual traditions, IS scholars who study economics of IS also argue that investments in organizational capabilities or structures are seen as necessary complementary resources to IS investments (Brynjolfsson et al. 1998; Brynjolfsson and Hitt 2000; Rai et al. 2006). Most recently, a broad sociomaterial perspective now has emerged as an important intellectual tradition that IS scholars can take credit for (Orlikowski and Barley 2001). This sociomaterial perspective is one that I will return to as I make a case that the IS community must turn the tables and become an exporter of theory as the role of digital technology radically alters the way firms innovate.

From Modularity to Generativity

Due to the continuing development of digital technologies, such as mobile communication, embedded computing, and miniaturization of microprocessors, combined with other technological developments including sensors and batteries, many everyday artifacts are increasingly becoming digital (Yoo 2010). Lyytinen and Yoo (2002) point out mobility, convergence, and massive scale as three key trends that define the emerging technological environment. Furthermore, as a result of the digitization of previously non-digital artifacts, a spectacular array of information is now digitally created, stored and consumed (Kallinikos 2006). All forms of content -- books, music, photos and maps, just to name a few -- are now available in digital format. Furthermore, types of information that were simply impossible or impractical to capture are now routinely captured, stored, and analyzed. Such digitalization of representations further enables and is enabled by small, yet increasingly potent, digital components that are becoming a standard part of previously non-digital artifacts such as books, cars, furniture, or buildings.

Yoo, Henfridsson and Lyytinen (2010) articulate three unique material characteristics of digital technology: (a) homogenization of data based on the use of binary digits for all types of data (Shannon and Weaver 1949), (b) re-programmability based on the von Neumann Computing Architecture, and (c) self-referentiality (i.e., one needs digital technology for digital innovations) (Kallinikos 2006). These three characteristics of digital technology have become the basis for making digital artifacts generative and highly evolving. Nearly limitless possibilities for recombination (or "mash-ups") of highly programmable digital artifacts through standardized interfaces enable the generativity of digital technologies (Arthur 2009; Lassig 2008). Furthermore, the staggering rate of improvement in the price-performance of digital devices has created a powerful positive feedback condition that accelerates the creation and diffusion of digital innovations. Unlike earlier physical resources that require extensive capital to acquire and operate, the universally available PC and Internet have democratized innovation as users and entrepreneurs from any part of the globe can participate in innovative activities, thus opening the floodgates to unbounded and generative innovations (von Hippel 2005). This further makes it possible for heterogeneous actors to pursue unique ideas that may not have been conceived by the original innovator, creating "wakes of innovations" (Boland et al. 2007). As a result, companies like Google, Facebook, and Apple deliberately create platforms that can be used to produce products and services that were not originally imagined by themselves. For example, one of Google's most popular services is Google Maps. Google Maps can be coupled with a host of heterogeneous hardware platforms, such as mobile phone, TV, cars, navigation systems, or digital cameras. In each of these devices the popular service can be used in a variety of ways. Many of the outcomes of such recombinations may not be what Google originally intended or thought possible when it first introduced Google Maps.

While the ideas of modularity and generativity share certain attributes, since both of them facilitate the design and production of a complex product through assemblage of subsystems and components, they do have some fundamental differences. A modular product begins with a *fixed* boundary. It begins with a centralized designer who creates an architecture and coordinates distributed actors to build subsystems. As such, with a modular design, modules are created through a *decomposition* of a complex product. That is, a product is designed first, then parts and sub-systems are designed later with standardized physical interfaces. Therefore, subsystem and components in modularity are *product-specific*.

To the contrary, generative digital modules are most often designed without fully knowing the "whole" design of how each module will be integrated with other modules (Gawer 2009). When Google Maps was first introduced, for example, the designers at Google did not know that it would be combined with thousands of location-based databases to create so called “mash-ups”. Nor were they aware when they developed Google MyMaps, that it would be used as an emergency coordination and communication capability during a natural disaster - until hurricane Katrina. Nor did they anticipate that Nikon engineers would create a digital camera integrated with Google Maps. It is the generativity, not the modularity, of digital products that makes them highly evolving. As such, generative digital products emerge through uncoordinated interactions among distributed and heterogeneous actors. While such interactions are facilitated by standardized interfaces (in the form of APIs) and powerful platforms, they are not centrally planned or coordinated (Tuomi 2002). Therefore, subsystems and components are *product-agnostic*. With generativity, then, the boundary of a product is unknowable and the product or service remains perpetually incomplete (Yoo et al. 2010). For example, smartphones remain essentially incomplete products when they are first purchased: users need to install applications to combine new affordances into an existing product; in fact, they remain incomplete throughout their lifetime as users continue to add and delete applications and change their functional capabilities.

The emergence of digitally-enabled generativity is fundamentally re-shaping the industrial landscape. The firms that once dominated the industrial economy, such as Kodak, GM, Cisco and Dell are being eclipsed by the emergence of new breed of firms like Google, Apple, Amazon and Facebook. Furthermore, the theories that once provided the guidelines for strategic management during the “age of modularity” (Baldwin and Clark 1997) can no longer offer effective guidance in this age of generativity. Of course, I am not suggesting that modularity is no longer relevant. What I argue instead is that the logic of modularity -- and the innovation strategies based on modularity -- alone cannot offer competitive advantage to firms who follow it. I conclude this essay by suggesting how the IS community can provide a leadership role in shaping the theoretical and practical discourse around digitally-enabled generativity.

Toward a Sociomaterial Theory of Generativity

Over the last three decades, the IS community has developed with a unique intellectual perspective that emphasizes the mutually reenforcing and constitutive relationship between social and technological forces (Leonardi and Barley 2008; Orlikowski and Scott 2008; Orlikowski and Barley 2001). As IS scholars struggle to build a coherent theoretical framework of the seemingly chaotic phenomena of generativity, they can draw on the sociomateriality perspective to better understand the nature and the consequences of generativity.

An important starting point is to open up the “black box” of technology and recognize the important role of materiality of digital technology (Orlikowski and Iacono 2001). Scholars in technology and innovation management often discuss digital technology as disruptive or radical innovations (Benner 2010; Benner and Tripsas 2012; Tripsas 2009). What is lacking in this research is a more precise and nuanced understanding of the nature of digital technology that enables and constrains activities that produce generative innovations. In the management literature, technology is often treated as an exogenous variable: it is somehow created *out there* independent of actors and enters into the discourse as an impenetrable foreign object. Orlikowski and Scott (2008) note that “technology is missing in action” in management literature on technology (p. 434). While such a position toward technology is problematic for management scholarship in general, it is entirely unsustainable when we study generativity enabled by digital technology. Scholars who study generativity need to explicitly incorporate the unique materiality of digital technology in order to gain a deeper understanding of the phenomenon.

Over time, IS scholars have developed a nuanced understanding of the *digital materiality* of technology. The digital materiality of an artifact is what the artifact can do to manipulate digital representations, using the software incorporated into it (Leonardi

2010; Yoo et al. 2012). Physical materiality of an artifact, in contrast, is the aspects of the artifact that can be seen and touched, that are relatively hard to change, and that implicates a specific context of time and place. For example, clothes have physical materiality because they can be worn, are hard to convert into a screwdriver, and carry social meanings of appropriate uses and settings for wearing them. What is particularly important in understanding the current wave of digital innovations is the incorporation of digital materiality into objects that previously had a purely physical materiality. An example would include a running shoe with a microchip. This shoe has a digital materiality in that the chip can record representations of movement in a digital format, while one without the chip cannot. The uniquely powerful affordances of digital technologies (Kallinikos et al. 2010; Yoo et al. 2010) allow designers to expand existing physical materiality by 'entangling' it with software-based digital capabilities (Yoo 2010; Zammuto et al. 2007). For example, a microchip in your automobile can be programmed to record your acceleration, braking and speed as you drive, communicate with your insurance company, and reduce your premiums for good driving patterns. In myriad ways, the digital materiality of artifacts enables generativity.

At the same time, IS scholars have demonstrated that the materiality of technology is deeply enmeshed with social practices in its creation and use (Orlikowski and Scott 2008; Pentland and Feldman 2007). Each time an actor designs or uses a digital technology, she mobilizes the traces of institutionalized social practices and taken-for-granted technology infrastructures. When a developer builds a location-based mobile application for Apple's iPhone, for example, she not only uses Apple's iOS APIs (application programming interfaces) and SDK (software development kit), but also draws in layers of standards many of which were created decades ago and fiber optics cables that are literally buried under the ocean. Furthermore, these technology artifacts are simultaneously enmeshed with social norms, organizing principles and role separations. All of these layers of social and material forces are entangled as they enable and constrain generative innovations.

Drawing on a sociomaterial perspective on generativity, IS scholars can study the nature of generativity. Generativity needs to be understood as a general sociomaterial system concept that defines how a finite number of sociomaterial building blocks can lead to the emergence of a seemingly infinite number of variations and speciations (Gaskin et al. 2010). The literature on modularity provides the vocabulary of architecture, interfaces and components as important elements of theories of innovations and technology management. Similarly, the emerging body of literature on generativity needs to offer a new vocabulary that can explain digital innovations. Using a sociomaterial perspective, scholars can develop such a vocabulary to compare different sociomaterial generative systems and to understand the *structure* of generativity. Scholars have discovered highly ordered underlying structures beneath the seemingly random patterns of evolution of generative systems such as the Internet (Barabási and Albert 1999) and biological cells (Barabási and Oltvai 2004; Ravasz and Barabási 2003). Using the vocabulary of sociomaterial generative systems, IS scholars might be able to discover similarly ordered patterns underneath the seemingly random patterns of continuing evolutions of digital products. Finally, we should be able to understand the *dynamics* of generativity. That is, we can use the vocabulary of sociomaterial generativity to characterize the evolutionary pattern of sociomaterial systems, and discover underlying generative mechanisms that give birth to the dynamic changes of the systems.

Conclusion

Pervasive and ubiquitous digitalization has brought new disruptive changes in the economy. In this essay, I argue that at the core of these disruptive changes is digitally-enabled generativity. Management scholars must offer new theoretical models and insights that guide management practices in the age of generativity that can extend, or perhaps supplant, the prevailing emphasis on modularity. IS scholars can provide significant contributions by drawing on the sociomaterial perspective, which has emerged as a robust intellectual tradition of the IS community, and by attending explicitly to the generative materiality of digital artifacts. This essay is a provocation for those IS scholars who are willing to stretch the boundaries of their intellectual imagination beyond the comfort of IS journals and conferences, and offers a promising path forward.

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