The New Organizing Logic of Digital Innovation: An Agenda for Information Systems Research

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Abstract

In this essay, we argue that pervasive digitization gives birth to a new type of product architecture, *the layered modular architecture*. The layered modular architecture extends the modular architecture of physical products by incorporating four loosely coupled layers of devices, networks, services, and contents created by digital technology. We posit that this new architecture instigates profound changes in the ways that firms organize for innovation in the future. We develop (1) a theoretical framework to describe the emerging organizing logic of digital innovation, and (2) an IS research agenda for digital strategy strategies and the creation and management of corporate IT infrastructures.

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1. Introduction

The miniaturization of hardware, increasingly powerful microprocessors, inexpensive and reliable memory, broadband communication, and efficient power management have made it possible to digitize key functions and capabilities of industrial-age products including cars, phones, TVs, cameras, and even books (Yoo 2010). With embedded digital capability, such products offer novel functions and remarkably improved price-performance ratios, transforming their design, production, distribution, and use. The phenomenal success of Apple's iPhone and Amazon's Kindle exemplifies how the digitization of well-established products like books sparks profound changes in the industrial structure and competitive landscape, blurring industry boundaries and creating new threats and opportunities. In the e-book case, firms from the computer industry, consumer electronics, Internet search, on-line retailing, book retailing, telecommunications, and publishing forming dynamic and overlapping alliances are being mingled together into a complex ecosystem. In this ecosystem, firms are busily developing new strategies that cater for the emerging market dynamics by competing head-to-head on some fronts (e.g., both Apple and Amazon sell hardware), and collaborating on others (e.g., Amazon offers reader applications for Apple's iPad). The digitization of the book is fundamentally re-shaping the structure that has underpinned book publishing for 200 years by bringing together firms from previously unrelated industries, ultimately changing the very idea of a book.

Over the last decade, information systems (IS) scholars have successfully examined the impacts of digital technology on the firm's strategy, structure and processes (Sambamurthy et al. 2003; Sambamurthy and Zmud 2000). Similar advances have been made to understand the role of information technology (IT) in creating business value and building sustainable competitive advantage (Kohli and Grover 2008; Nevo and Wade 2010). However, digital technology's transformative impact on industrial-age products has remained surprisingly unnoticed in the IS literature. In fact, the IS literature rarely considers how product architectures – the arrangement of functional elements, the mapping from functional elements to physical components, and the specification of interfaces among components (Ulrich 1995, p. 420) – affect the firm's strategic choices and related IT deployments. Neither has the literature considered the emergence of new organizing logics – i.e., "managerial rationale for designing and evolving specific organizational arrangements in response to an enterprise's environmental and strategic imperatives" (Sambamurthy and Zmud 2000, p. 107) – spurred by changes in product architectures due to digital technology. This is unfortunate because changes in product architecture and organizing logic reshape the landscape of IS strategy and use in firms.

In this essay, we propose that digital technology instigates a new type of product architecture: *the layered modular architecture*. We conceive the layered modular architecture as a hybrid of the modular architecture of a physical product and the layered architecture of digital technology. The modular architecture provides a scheme by which a physical product is decomposed into loosely coupled components, attributed functionality, and interconnected through pre-specified interfaces (Baldwin and Clark 2000; Ulrich 1995). The layered architecture of digital technology (Adomavicius et al. 2008; Gao and Iyer 2006) is embedded into physical products, enhancing product functionality with software-based capabilities. Similar to modularity's impact on industrial organization (Baldwin and Clark 2000; Langlois 2003), we argue that the emergence of the layered modular architecture generates profound changes in a firm's organizing logic and innovation. To this end, we develop (1) a theoretical basis to characterize the organizing logic of digital innovation based on the layered modular architecture, (2) and formulate an IS research agenda to study the new logic and its effects on strategy and corporate IT infrastructures.

2. Digital Innovation

2.1 Defining Digital Innovation

Following Schumpeter (1934), we define digital innovation as the carrying out of new combinations of digital and physical components to produce novel products. Our use of the term digital innovation thus implies a focus on *product innovation*, distinguishing it from extant IT innovation research that has been primarily occupied with *process innovation* (Swanson 1994). A necessary, but insufficient condition for digital innovation is that the new combination relies on *digitization*, i.e., the encoding of analog information into digital format. Digitization makes physical products programmable, addressable, sensible, communicable, memorable, traceable, and associable (Yoo 2010). Digital innovation furthermore requires the firm to revisit its organizing logic and its use of corporate IT infrastructures.

Consider the e-book example: digitization has created a necessary condition for digital innovation among a range of firms capable of engaging in digital publishing. The previously non-digital product – the book – now embeds digital capabilities like communication, memory, programmability, traceability (e.g., Amazon can track how long a reader is looking at each page, and readers can find out who else underlined a particular sentence), and so on. Despite the short history of the e-book, there are already signs of changes in the organizing logic of publishing, whereby publishers' tight control over the content creation, production, and distribution is deteriorating. In the early stages of the e-book evolution, Kindle replaced an old physical artifact with a new one with similar (although digitally-enabled) form factors. Kindle's main attraction was the radically reduced marginal production and distribution costs, and its ability to hold thousands of books in a single unit. With the introduction of iPad some 18 months later, however, e-books challenge the vertically integrated model of publishing. The e-book is now fully disintegrated into distinct layers of devices, networks, services, and contents – a fate already experienced by the digital camera and mobile phone, and likely to be repeated with television with products like Google TV and Apple's iTV. Following the disintegration of the vertical model, new conceptions of a book are likely to sprout as other digital components such as interactive multimedia, GPS, social media applications, and accelerometers are being integrated into e-books.

2.2 Key Characteristics of Digital Innovation

In order to understand the nature of digital innovation, one must consider how digital technology differs from earlier technologies. Here we note three unique characteristics: (1) the re-programmability, (2) the homogenization of data, and (3) the self-referential nature of digital technology.

First, based on the von Neumann Architecture, a digital device consists of a processing unit that executes digitally encoded instructions, and a storage unit that holds both instructions and data being manipulated in the same format, and in the same locations (Langlois 2007). As long as users agree on the meaning of the digital data and have wits to come up with new instructions to manipulate the data, the architecture offers flexibility in the way data is manipulated. Thus, unlike analog technology, a digital device is *re-programmable*, enabling separation of the semiotic functional logic of the device from the physical embodiment that executes it. The re-programmability allows a digital device to perform a wide array of functions (like calculating distances, word processing, video editing, and web browsing).

Second, an analog signal maps changes in a continuously varying quantity on changes in another continuously changing quantity. As such, analog data implies a tight coupling between data (e.g., texts and pictures) and special-purpose devices, storing, transmitting, processing, and displaying the data (e.g., book and camera). In contrast, a digital representation maps any analog signal into a set of binary numbers, i.e., bits (a contraction of binary digits). This leads to a *homogenization of all data* accessible by digital devices. Any digital contents (audio, video, text, and image) can be stored, transmitted, processed, and displayed using the same digital devices and networks. Furthermore, unlike analog data, digital data originate from heterogeneous sources, and can at ease be combined with other digital data to deliver diverse services, dissolving product and industry boundaries. Thus, the homogenization of data, along with the emergence of new media, separates the content from the medium.

Finally, *self-reference* means that digital innovation requires the use of digital technology (e.g., computers). Therefore, the diffusion of digital innovation creates positive network externalities that further accelerate the creation and availability of digital devices, networks, services, and contents (Benkler 2006; Hanseth and Lyytinen 2010). This, in turn, fosters further digital innovation through a virtuous cycle of lowered entry barriers, decreased learning costs, and accelerated diffusion rates. The drastic improvements in the price-performance of computers and the emergence of the Internet have made the digital tools necessary for innovation affordable to a broad spectrum of previously excluded economic and innovative activity. Digital technology, therefore, has democratized innovation and almost anyone can now participate.

2.3 The Layered Architecture of Digital Technology

The characteristics of digital technology pave the way for the layered architecture (Adomavicius et al. 2008; Gao and Iyer 2006), perhaps best exemplified by the Internet. The layers manifest two critical separations: (1) the separation between device and service due to re-programmability, and (2) the separation between network and contents due to homogenization of data.

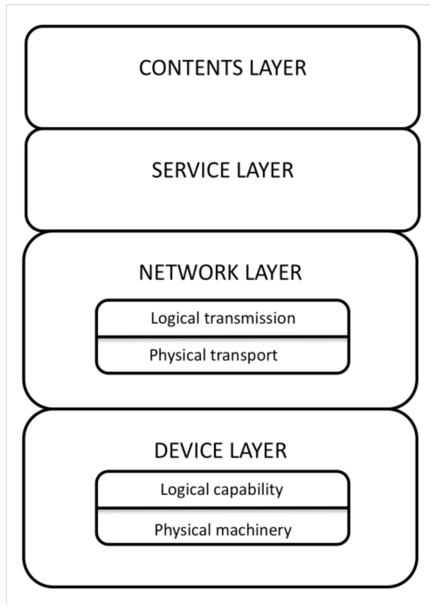


Figure 1. The Layered Architecture of Digital Technology

As illustrated in Figure 1, the layered architecture consists of four layers: devices, networks, services, and contents (Benkler 2006; Farrell and Weiser 2003). The device layer can be further divided into a physical machinery layer (e.g., computer hardware) and a logical capability layer (e.g., operating system). The logical capability layer provides control and maintenance of the physical machine and connects the physical machine to other layers. The network layer is similarly divided into a physical transport layer (including cables, radio spectrum, transmitters, and so on), and a logical transmission layer (including network standards such as TCP/IP or P2P protocols). The service layer deals with application functionality that directly serves users, as they create, manipulate, store, and consume contents. Finally, the contents layer includes data such as texts, sounds, images, and videos stored and shared. The contents layer also provides meta-data and directory information about the content's origin, ownership, copyright, encoding methods, content tags, geo-time stamps, and so on.

The four layers represent different design hierarchies (Clark 1985) and the individual design decisions for components in each layer can be made with minimum consideration of other layers. Therefore, designers can pursue combinatorial innovation by gluing components from different layers using a set of protocols and standards to create alternative digital products (Gao and Iyer 2006). Combined with the rapid diffusion of personal computers and the Internet, the layered nature of digital technology has brought unprecedented levels of generativity (Tuomi 2002; Zittrain 1998).

While the layered architecture has been discussed in IS literature (Adomavicius et al. 2008; Gao and Iyer 2006), little attention has been paid to its implications for product innovation. The digitization of physical products challenges some of the fundamental assumptions about product architecture and organizing logics. Next, we will discuss how it introduces a new type of product architecture.

3. Layered Modular Architecture

3.1 Modular Architecture

Two architectures have dominated physical product design: integral and modular. An integral architecture is characterized by a complex and overlapping mapping between functional elements and physical components, where the interfaces between components are not standardized, making them tightly coupled (Ulrich 1995). As a result, changes in one part of a product typically affect the rest of the product, often unpredictably. The tight coupling among components in an integral architecture renders high performance and quality, which is important for certain products such as sports cars and high-end electronics.

To the contrary, a *modular architecture* is characterized by its standardized interfaces between components. Modularity is a general characteristic of a complex system, referring to the degree to which a product can be decomposed into components that can be re-combined (Schilling 2000). Rooted in Simon's design theory (Simon 1996), a modular architecture offers an effective way to reduce complexity and to increase flexibility in design by decomposing a product into loosely coupled components interconnected through pre-specified interfaces (Baldwin and Clark 2000). Although just nearly decomposable in practice (Simon 2002), an ideal modular architecture implements one-to-one mapping between functional elements and physical modules (Ulrich 1995).

Shifts in product architecture cause shifts in the organizing logic of a firm. With an integral product architecture, the dominant organizing logic is the vertically integrated hierarchy, wherein a single firm carries out the majority of innovation required to compete. Here, components are often co-specialized with each other (Langlois 2003; Teece 1993). The key sources of value creation are economies of scale and scope, emanating from overwhelming endowments to physical resources (Barney 1996). With an integral architecture, dominant approaches to competitive strategy are accordingly product positioning (Porter 1980), which distinguishes market scope and strategic strength as key parameters for determining the appropriate strategy. In contrast, a modular architecture leads to vertical disintegration of the firm's design and production functions, as seen in the change of the industrial organization of the computer (Baldwin and Clark 2000; Langlois 2007), software (Chandler and Cortada 2000), and telecommunication industries (Tuomi 2002). Leveraging radically reduced communication and coordination costs enabled by IT (Malone 2004), firms like Cisco, Dell, and Nokia have heavily invested in corporate IT infrastructures that leveraged network technologies to realize net-enabled value networks (Sambamurthy and Zmud 2000; Wheeler 2003) whereby design and production activities can be distributed among a network of firms (Nohria and Eccles 1992). The key source of value creation is the agility that flows from the ability to rapidly re-combine components of a modular product architecture positioned within a single design hierarchy without sacrificing cost or quality (Sambamurthy et al. 2003).

3.2 Layered Modular Architecture

As firms increasingly embed digital components into physical products, the *layered modular architecture* emerges. The layered modular architecture is a hybrid between a modular architecture and a layered architecture, where the degree by which the layered architecture augments the generativity to the modular architecture forms a continuum. On one end, we have the traditional modular architecture that is based on a fixed product boundary. The modular design of such a product is initiated by decomposing the product into components following a functional design hierarchy (Clark 1985; Baldwin and Clark 2000). Therefore, the relationships between the product and its components are *nested* and *fixed*. Given the nested nature of relationships and the fixed product boundary, aggregating all components will make up the whole product. In addition, in a modular architecture, the design of a component is driven by the functional requirements created within the context of a given product. That is, components in a modular architecture are *product-specific*[1]. Furthermore, components are designed and produced by specialized firms that all share product-specific knowledge. The primary goal of modularity is to reduce complexity and to increase flexibility (Schilling 2000; Simon 1996). The flexibility is accomplished through substitutions of components within a single design hierarchy. For example, a single lens reflex (SLR) camera can be fitted with multiple lenses using a standardized mounting interface, increasing the camera's flexibility. Thus, the flexibility of a modular architecture comes from the *differences in degree*.

On the other end, we have the full-blown layered modular architecture that does not have a fixed boundary at the product level. The design of a component thus requires little product-specific knowledge. That is, components in a layered modular architecture are *product-agnostic*. Google Maps, for example, consist of a bundle of contents (i.e., maps) and service (e.g., search, browse, traffic, and navigation) layers with different sets of interfaces (i.e., APIs). While Google Maps can be used as a standalone product, it can simultaneously be used in a variety of different ways, bundled with a host of heterogeneous devices, such as desktop computers, mobile phones, TV, cars, navigation systems, or digital camera. In this regard, a component design in a layered modular architecture is not derived from a single design hierarchy of a given product. Instead, a product is inductively *enacted* by orchestrating an ensemble of components from a set of heterogeneous layers, each of which belongs to a different design hierarchy (Clark 1985). Therefore, the designers of components in a layered modular architecture cannot fully know how the components will be used. That is, Google's designers cannot fully anticipate all possible ways Google Maps as a component will be used. As such, a layered modular architecture offers generativity, i.e., "a technology's overall capacity to produce unprompted change driven by large, varied, and uncoordinated audiences" (Zittrain 2006, p. 1980). Generativity in a layered modular architecture is accomplished through loose couplings across layers whereby innovations can spring up independently at any layer

[1] Of course, certain low-level components can be commodities used in multiple products.

leading to cascading effects on other layers (Adomavicius et al 2008; Boland et al 2007). Whereas components in a modular product fall under a single design hierarchy, components in a layered modular architecture participate in multiple heterogeneous design hierarchies. Unlike the flexibility of a modular product that produces *differences in degree*, the generativity of a layered modular product produces *differences in kind*. For example, utilizing available hardware resources, a digital camera with a layered modular architecture can be used not only as a camera, but also as a video player, photo editor, internet client, and in many other ways. Therefore, a layered modular product remains fluid and is open to new meanings. Unlike the purely layered architecture (Gao and Iyer 2006), however, the generativity of a digitized product with a layered modular architecture is constrained by characteristics of the physical components of the product (e.g. form factors and availability of certain physical components).

The modular architecture and the layered modular architecture form the two end points of a continuum as firms embed digital components (see Figure 2) into their products. Traditional industrial-age, single-purpose, products manifest one end of the spectrum, while conventional digital products with general computer hardware forms another end. And many digitized products will fall somewhere in the middle.

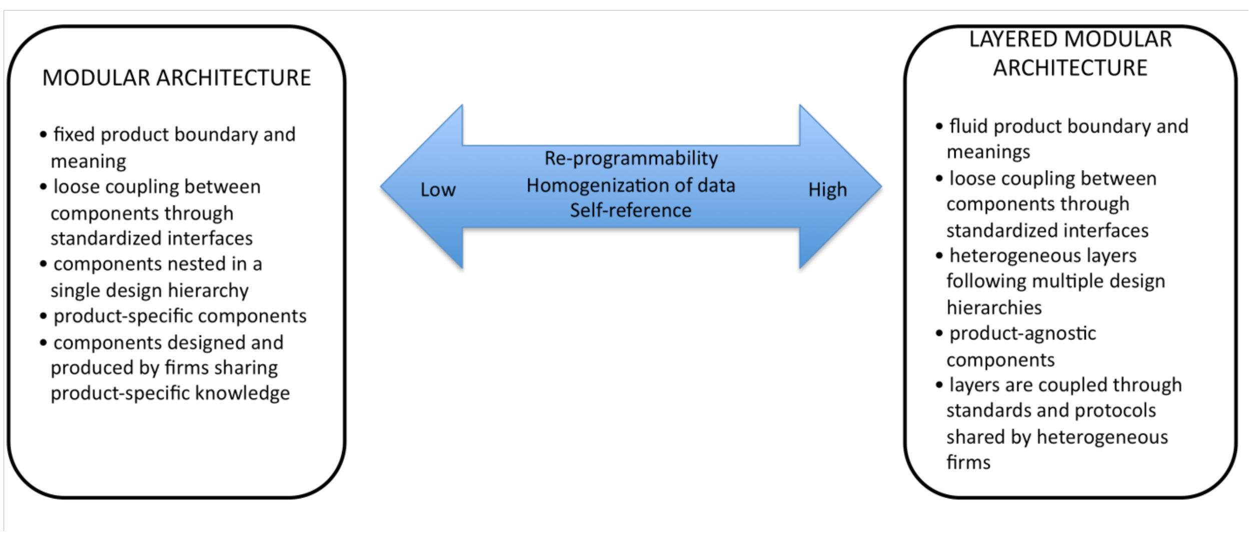


Figure 2. The Layered Modular Architecture Continuum

3.4 The Organizing Logic of Layered Modular Architecture

With a layered modular architecture, a digitized product can be simultaneously a product and a platform. For instance, an iPad can be used as a complete product out of the box. Yet, as a platform, it enables other firms to invent novel components such as new apps and peripheral hardware accessories with which its basic functionality can be expanded. Therefore, firms operating in a competitive landscape shaped by layered modular architectures invest in *digital product platforms* that cater for multi-sided markets and help build vibrant ecosystems (Eisenman et al. 2006). A digital product platform encompasses typically a particular range of layers (e.g., content and service layers) that can function as a new product, but simultaneously enable others to innovate upon (Gawer and Cusumano 2008) using firm-controlled *platform resources* (e.g., SDKs and APIs[2]). For example, as most subsystems of an automobile are becoming digitized and connected through vehicle-based software architectures, an automobile has become a computing platform on which other firms outside the automotive industry can develop and integrate new devices, networks, services, and content (Henfridsson and Lindgren 2010).

A digitized product with a layered modular architecture can serve as a platform at one layer courting for its own installed base, while serving as a component at another layer. Due to the dynamic nature of the layered modular architecture, the same firms can compete on one layer and peacefully co-exist on other layers. For example, Apple's iPad and Amazon's Kindle directly compete at the device layer. The two firms also compete at the content layer with the iBook and Kindle stores. At the same time, Amazon offers its application for iPad, thus becoming a component provider at the service layer of the iPad. Similarly, Apple's iPhone (device layer), along with other mobile devices, has been an important component for Google's mobile search platform (service layer). At the same time, Google Maps (service and contents layers) is an important component of the iPhone platform. As Apple introduced its own mobile search and advertisement systems, however, Apple and Google began to compete directly on the service layer. Similarly, as Google introduced its own Android-based mobile phone, Apple and Google started to compete at the device layer.

Within a layered modular architecture, a firm seeks to attract heterogeneous actors to design and

[2] SDK stands for Software Development Kit; API stands for Application Programming Interfaces.

produce novel components on layers outside of its digital product platform. The generativity of a layered modular architecture, then, comes from a firm's ability to design a product platform that can attract a large number of heterogeneous and unexpected components that belong to different design hierarchies. The greater the heterogeneity, the more generative the platform becomes. Although it is theoretically possible to pursue such generativity within the closed boundary of a single firm or its existing supplier network, the firm's ability to do so is practically limited due to its economic, structural, cognitive, and institutional constraints. Therefore, even though the layered modular architecture is pregnant with the generative potential, this potential is only fully realized when it is paired with a new organizing logic that involves heterogeneous actors, many of whom pursue their own innovation strategies. As a result, innovation within a layered modular architecture is *distributed* not only among firms of the same ilk, but also across firms of different kind. These firms' innovation activities reciprocally and recursively influence each other, creating the image of "wakes of innovation" (Boland et al. 2007). Accordingly, we characterize the organizing logic for a layered modular architecture as *doubly distributed.* It is *distributed,* because the primary source of value creation is the generativity that comes from unbounded mix-and-match capability of heterogeneous resources across layers. It is *doubly* distributed, because (a) the *control* over product components is distributed across multiple firms, and (b) the product *knowledge* is distributed across heterogeneous disciplines and communities. In this environment, an essential capability is the ability to design a digital product platform to inspire and mobilize a vibrant and doubly distributed network to maximize the generative potential of the layered modular architecture. In managing such a network, a firm needs to have the capability to create new meanings of its products and services (Verganti 2009) by constantly re-defining the product boundaries through active re-shaping of the product ecology (Kusuoki and Aoshima 2010).

4. Information Systems Research Agenda and Key Research Questions

What should be the IS research agenda as physical products become digitized? The key question here is how we can understand the consequences of digital innovation and the emergence of the layered modular architecture on strategy and corporate IT infrastructures. In what follows, we belabor the research challenges and present sample research questions for both themes.

4.1 New Strategic Frameworks

With the digitization of products and the emergence of the layered modular architecture, firms face new competitive dynamics. In this new environment, digital technology is an integral part of strategy formulations. Accordingly, IS scholars need to question and complement their received models of aligning IT to business strategy, identifying core IT resources, and managing IT as a standardized commodity. Instead, IS scholars must imagine new digital strategy frameworks that identify new sources of value-creation such as generativity, heterogeneity, creating digital product platforms and meaning-making capability. We need new strategic frameworks that are aimed at deliberately harnessing unique capabilities of digital technology that are embedded into products to gain competitive advantage. We here note the following research challenges.

First, the digitization of products blurs product and industry boundaries. In fact, blurring boundaries is what firms like Google and Apple deliberately pursue. Therefore, assumptions about a stable industry and a fixed and bounded product will limit the effective exploitation of digital technology. We need new theoretical frameworks for competitive strategy and the development of digitized products that are based on dynamic and fluid views on products. This demands us to revisit traditional theoretical devices such as generic strategies, product life cycle, and dominant product design. We need to articulate new competitive strategies and envision new roles of IT in shaping those strategies, asking: *what are new generic strategies of digital innovation* and *what are core design principles of digital technology for the generic strategies?* With this line of inquiry, we need to explore a set of fundamental strategic roles of embedded digital technology in creating competitive advantage of through digital innovation.

Second, since the layered modular architecture represents a range of possibilities of embedding digital components into a physical product as shown in Figure 2, it represents a strategic choice for firms seeking digital innovation. An important research question, then, is: *what are the technical and strategic dimensions that influence the relative position of a digitized product on the continuum of layered modular architecture and their strategic consequences?*

Third, as we noted earlier, with layered modular architectures, firms create digital product platforms to control key components or particular combinations of components within certain layers. Such strategic control of key components can render competitive advantage. Specifically, firms need to constantly ask the questions: (a) what needs to remain open and what needs to be closed in a digital product platform, (b) how to identify and control the core components that are of strategic importance and (c) how to build effective incentives for different firms to join the product platforms? Therefore, an important research topic is to understand *how can a firm strategically control its digital product platform and how does such controls evolve over time*?

Fourth, although a layered modular product can function as a platform and a component simultaneously, strategically not all firms can afford to pursue both of them at the same time. For example, small start-up firms may need to pursue a strategy focusing on components until it gains enough stable user base across multiple platforms. Similarly, whether a firm migrates into a layered modular architecture from a physical product or a software product will influence its digital innovation strategy. At the same time, firms must carefully design its digitized products so that its present decision does not constrain its future strategic options with digital product platforms. Therefore, an important research question is: *what are the factors that influence a firm's strategic choices on digital product platforms?*

Finally, with doubly distributed innovation networks, a firm's ability to attract heterogeneous and unexpected firms to build various components has become strategically important. Key strategic resources that the firm can control in this domain is the design of technical boundary resources like APIs and SKDs and social boundary resources like incentives, intellectual property rights and control. Therefore, design decisions of these boundary resources bear strategic importance. Therefore a critical research question is: *what are the strategic roles of technical boundary resources such as APIs and SDKs and social boundary resources like incentives, intellectual property rights and control with a layered modular architecture?*

4.2 Corporate IT Infrastructures

Since the late 70's, corporate IT infrastructures have been critical for the viability and operations of modern organizations. Corporate IT infrastructures provide the foundation of the IT resources (both technical and human) shared throughout the firm (Broadbent et al. 1999). As product architectures and organizing logics evolve, the role of corporate IT infrastructures evolves as well. Vertically integrated firms, competing with integral products, primarily built corporate IT infrastructures that helped automate manufacturing and back-office processes to maximize the economies of scale and scope. They rested on the support of transaction systems, management information systems, decision support systems, and executive information systems to increase efficiency, and to ensure the integrity and reliability of centralized control. As modular architectures emerged, however, the corporate IT infrastructure expanded to support net-enabled enterprise processes (Sambamurthy and Zmud 2000; Wheeler 2003). The ability to manage the reach and scope of IT in supporting critical inter- and intra-organizational processes became a key differentiator in building competitive capability (Sambamurthy and Zmud 2000). To create these capabilities, firms built collaborative systems, knowledge management systems, and e-business systems to coordinate activities of a distributed network of specialized firms.

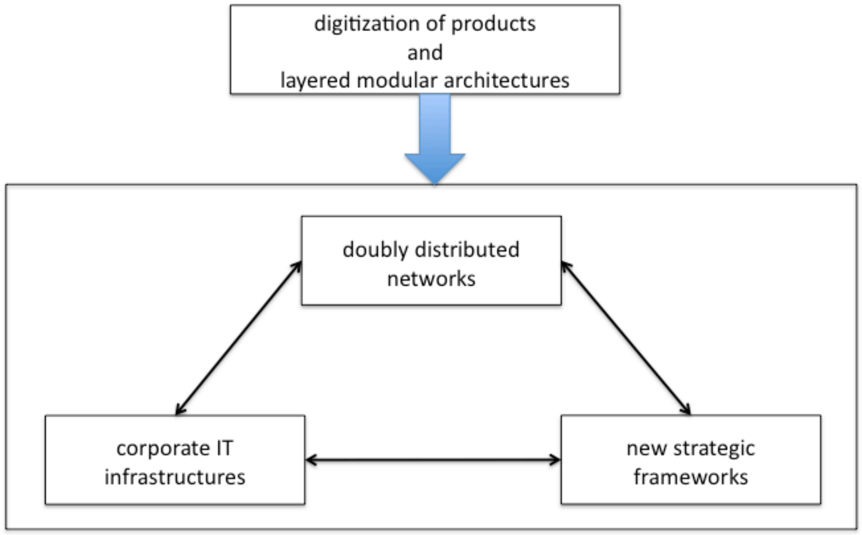
As firms start competing with layered modular products, the role of the corporate IT infrastructures is likely to transform again. In particular, doubly distributed innovation networks as the organizing logic simultaneously entail the question of how to distribute organizational control in a new way, and how to cope with the increased heterogeneity of knowledge resources that stem from multiple and conflicting design hierarchies. With layered modular architectures, the types of knowledge resources needed for innovation cannot be fully known *a priori,* and interactions are indeterminate and emergent. In addition, each firm in a doubly distributed network follows its unique innovation trajectory, while possibly participating in multiple doubly distributed networks. The trajectories and accumulated knowledge become interwoven over time, generating a staccato-like pattern during innovation as the firms influence one another reciprocally and non-linearly. For example, in the mobile media market, a myriad of previously unconnected firms (e.g., mobile network operators, software companies, content providers) must weave together their distinct mental schemes, business models, and heterogeneous infrastructures while establishing new products. These changes create the following research challenges for IS scholars.

First, in doubly distributed innovation networks, the locus of innovation moves outside of the boundary of a single design hierarchy. Vertically integrated firms used IT to maximize the strategic, tactical, operational deployment of internal resources to support innovation. Networked firms, on the other hand, used IT to maximize the value within the network by coordinating and synchronizing data and processes among firms within the boundary of a single network. In both cases, however, design activities of all components fall under the auspices of a single design hierarchy. With the layered modular architecture, however, innovation activities cut across multiple design hierarchies. Each design hierarchy is populated with its own unique IT tools and capabilities (Boland et al., 2007). Furthermore, as the meaning of a digitized product generatively expands, the edge of the network evolves constantly thus amplifying the challenge of heterogeneity. Therefore, traditional centralized tools to support knowledge management and virtual teams need to be augmented with new tools that can handle heterogeneity and discontinuity in knowledge. An important research challenge, thus, is: *what are the characteristics of IT that support generative and heterogeneous knowledge work in doubly distributed innovation networks with multiple and often conflicting design hierarchies?*

Second, layered modular architectures demand IT infrastructures that can leverage ubiquitous availability of a wide and varying range of digital capabilities. Some of these capabilities are created and controlled within the firm, while others are garnered through the 'cloud' (Lyytinen and Yoo 2002). The main aim of the IT infrastructure is to support generativity by managing, coordinating, and connecting to heterogeneous knowledge resources. In order to enable the mix-and-match across loosely coupled layers, digital representations within and across these layers need to be re-combined to create families of new digital representations and services. Therefore, unlike earlier corporate IT infrastructures, the new IT infrastructure for the layered modular architecture cannot be easily bounded and separated from the industry and society-wide infrastructures. IT infrastructures are, thus, increasingly difficult to coordinate from a single governance point such as the corporate CIO, as they span beyond the boundaries of the single corporation. Traditional rules and mechanisms of alignment, centralization, and cost control need to be augmented with new governance principles such as architectural models and control, software-enabled control mechanisms, new incentive mechanism, and so on. Furthermore, firms will be challenged on how to effectively manage and coordinate distributed and dynamic processes of designing and maintaining corporate IT infrastructures. Therefore, a new research challenge is emerging for IT governance: *what are the forms of governance to effectively manage and organize the evolution of corporate IT infrastructures that support doubly distributed networks?*

Third, as the role of the IT infrastructures changes, so do the development approaches. Vertically integrated firms used lifecycle models and structured design methodologies to build software. Within networked firms, system development approaches focused on shared data objects, message exchange protocols, and related services and their governance. Along with approaches emphasizing enterprise-level modularity like enterprise resource planning systems, agile methods were developed to cope with the increased pace of change. With doubly distributed networks, development approaches need to focus on how to incentivize and coordinate heterogeneous communities through sharing of boundary resources and knowledge flows. The role of boundary resources such as APIs and SDKs in orchestrating innovation that goes beyond a single firm or a network (Swanson 1994) will increase. Increasingly, the value of IT lies in its integration with and expansion towards third-party components. Furthermore, the development contexts of layered modular products are likely to be ripe with less forgiving and more heterogeneous hardware making it critical to design and diffuse high quality platform resources. An important research challenge is to explore: *what are the appropriate methodological and technological principles of the design of technical boundary resources that help sustain continued developments of novel components in doubly distributed networks*?

Finally, due to the dynamics of the layered modular architecture and doubly distributed networks, the familiar context of system development with clearly defined roles is disappearing. In contrast, the new context of system development is created by heterogeneous firms pursuing conflicting goals, participating in multiple design hierarchies, and intertwining a range of innovation trajectories. Therefore, a critical research question is: *what are the appropriate principles that govern the social context of developments of*



boundary resources and digital components in doubly distributed innovation networks?

Figure 3. A Conceptual Framework of New IS Research Agenda with Digital Innovation

Figure 3 shows an overall conceptual framework of digital innovation based on our discussion so far. Digitization of physical products and the emergence of layered modular product architectures, thus, lead to the doubly distributed networks as the organizing logic inviting the creation of new strategic frameworks and new corporate IT infrastructures that all mutually influence each other. Table 1 summarizes research challenges in the two broad themes we discussed.

Table 1: Research Themes and Research Questions with the Layered Modular Architecture

Research Themes	Example research questions
1.1. **New Strategic Frameworks**	• what are the generic strategies of digital innovation and core design principles of digital technology for those strategies? • what are the technical and strategic dimensions that determine the relative position of a digitized products on the continuum of the layered modular architecture? • how can a firm strategically control its digital product platforms and how does such controls evolve over time? • what are the factors that influence a firm’s strategic choices on digitized product platforms? • what are the strategic roles of technical and social boundary resources with a layered modular architecture?
1.2. **Corporate IT infrastructures**	• what are the technical characteristics of IT that support generative and heterogeneous knowledge works in doubly distributed networks? • what are the forms of governance of corporate IT infrastructures that support doubly distributed networks? • what are the methodological and technical principles of the design of technical boundary resources for vibrant and sustainable doubly distributed networks? • what are the social principles for the developmental context of boundary resources and digital components in doubly distributed networks?

5. Conclusions

The IS field has grown significantly since its birth some 40 years ago. At the same time, our society has experienced remarkable change due to digital technology. The origin of the field began by asking: how should firms use the emerging computing power to improve the efficiency of vertically integrated firms? Accordingly, a majority of research in the early days of *Information Systems Research* focused on improving the efficiency of internal operations and decision-making. As firms began to use the power of IT to transform vertical hierarchies into networks, we saw a remarkable shift in the community's interest towards supporting net-enabled firms driven by modular architecture. The third decade of the journal starts with another new research vista fueled by digitized products. We now create digitized products with loose couplings across devices, networks, services and contents in an irrevocable way. So far, we have only seen the early forms of such digitized products, and therefore can only dimly observe the forms of the emerging organizing logic of digital innovation. We remain emboldened, however, that as the transformative power of digital technology accelerates, it will become the new epicenter of our inquiries, inviting us in novel theorizing and empirical research. A new exciting era will dawn to the IS community as it continues to make sense of the role of digital technology in human enterprise.

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