

Desperately seeking the Infrastructure in IS Research: Conceptualization of “Digital Convergence” as co-evolution of social and technical infrastructures

David Tilson
University of Rochester
david.tilson@simon.rochester.edu

Kalle Lyytinen
Case Western Reserve University
kalle@po.cwru.edu

Carsten Sørensen
London School of Economics
c.sorensen@lse.ac.uk

Abstract

Large scale penetration of digital technologies led them to join roads, electricity, and water distribution, as essential infrastructures of modernity. “Digital convergence” refers to these technologies’ wide ranging effects on people’s lives, work, and interactions. Yet conceptions from diverse fields reveal no universally accepted understanding of this term. An examination of historical developments leading up to the Internet era reveals mutual dependence between technical infrastructures and diverse social arrangements including industry, regulatory, and market structures. A set of criteria for the definition of digital convergence (and divergence) is formulated. These provide a working definition that reveals the essential, pervasive and interactive reconfiguration of modern society’s technical and social infrastructures due to digitization. A layer-based model is presented as one possible way of breaking up an increasingly interconnected socio-technical world into separate domains that allow meaningful study. We call for action to address the paucity of recent Information Systems (IS) research into the infrastructures that provide the foundations upon which all modern information systems build.

operation of a society or enterprise.” The digital technologies that emerged in the late 20th century joined roads, electricity, and telephone networks as essential infrastructures of modernity. In the last two decades the infrastructural features of digital technologies have been instrumental in transforming industries built in the earlier analog era. Often the creation and impact of these infrastructures is more fundamental to generating change than that of any particular application or system. As a result, a rich debate on infrastructure evolution and convergence has emerged amongst technology practitioners, investors, and in a variety of academic fields [8].

The IS field has generally paid little attention to information infrastructures despite extensive reliance on computing infrastructures and broadband communications; with notable exceptions [9-12]. IS research in, for example, computer mediated communications, media choice, virtual teams, and e-markets explore phenomena directly influenced by infrastructure evolution. Even less IS research seeks to understand the empirical and theoretical aspects of digital convergence [4]. Our analysis of 260 MIS Quarterly articles confirmed the lack of research into infrastructure evolution and digital convergence.¹

1. Introduction

Thousands of pages have been written in the academic, practitioner, and popular literatures about the effects of digital technologies [e.g. 1, 2, 3]. The term *Digital Convergence* has been in use for over 30 years [4] and often refers to wide ranging effects and processes [5-8]. As a result of the complexity of the phenomena that the term has been used to portray no universally accepted understanding has emerged. This paper seeks to understand the essence of the term using an infrastructural perspective. We call for the IS field to begin seriously examining the range of phenomena labeled as digital convergence.

The Compact OED defines infrastructure as “the basic physical and organizational structures (e.g. buildings, roads, and power supplies) needed for the

¹ A total of 260 research articles dealing directly with phenomena of interest to the IS field were published between December 1998 and June 2009 in MISQ (there were also 160 introductions, editorials, and other miscellaneous articles). One of the authors read each article’s abstract and assigned a category according to the research stream to which it claimed to belong (e.g. DSS, CMC, value of IS, etc). Unsurprisingly these categories could be readily mapped to the five IS core research areas identified by Sidorova et al [13]. The same author also reviewed each article’s abstract to assess whether it could be considered to have anything to say directly about digitization, digital convergence, or the role of infrastructure. To our surprise the word *convergence* appears only once in the article abstracts and its use has nothing to do with digital convergence. The word *infrastructure* appears in 10 abstracts, but in no case refers a societal level of analysis. It is used as an industry level proxy in discussing inter-organizational information systems. We found some articles recognizing network effects [14] and how organizations negotiate the ways they interact using information infrastructures at industry [15] and cross industry [16], or how they change due to the adoption of e-markets [17]. Some have noted disruptions caused by new infrastructural features of Internet

We find this state of the art somewhat puzzling and challenging. Our credo in this paper is that infrastructures as a class of IT artifacts *sui generis* should be taken seriously in IS research. Though infrastructures tend to fade into the background of organizational life [12] they should not be allowed to fall off the IS research agenda. We echo Orlikowski and Iacono's [23] call for the IS field to take seriously the specific characteristics of the IT artifact and wish to further strengthen the focus on infrastructure implicitly covered in their "ensemble view" category. One part of this challenge is to distinguish and clarify what are the specific properties of various sets of artifacts like infrastructures. One such set of properties is the nature of the infrastructural change and its drivers often denoted by the term 'digital convergence.' Our goal here is to explore the meaning of the term 'digital convergence' and how its interpretation helps shape our view of IS research and its directions. In particular, we show that during the first wave of digitization the tight coupling of analog technologies and industry structures remained. In the second wave the inherent flexibility of digital techniques resulted in network and device convergence as well the convergence of the media and communications industries. The third wave of digitalization, in contrast, unleashes the flexibility not just of digital representation, but also the malleability of software and the general purpose computer – resulting in a vast increase in both business possibilities and capabilities. As a result a rapid divergence is emerging in how service creation, distribution, and use occurs, which, paradoxically, is built upon the convergence around the bit. We also argue that the tension between convergence and divergence, driven by increasingly ubiquitous and capable digital infrastructures, affects all the phenomena studied by the IS field. It is therefore vital that the field pays attention to the underlying broad drivers of socio-technical digital change rather than only to specific local manifestations of that change.

The remainder of the paper is organized as follows. The next section gives a short history of analog and digital technologies and the media and communications industries that grew up around them.

Several conceptualizations of digital convergence are reviewed in section 3 and an infrastructural view developed. Here, infrastructures constitute dynamic and continuously evolving elements in a web of diverse social and economic actions, which they simultaneously constrain and enable. As a rough

working characterization we define digital convergence as an essential, pervasive and interactive reconfiguration of the technical and social information infrastructures of modern society. Next, a three-layer model of infrastructure is presented as a potential framework for studying the interdependencies in socio-technical infrastructures underlying the inexorable growth of interconnections between the IS field's traditional phenomena of interest and the wider socio-technical world being transformed by digital convergence. Further implications for IS research are discussed in the final section.

2. From digitizing to digitization²

2.1 Analog technologies and social structures

An analog signal maps changes in one continuously varying quantity (e.g. air pressure changes corresponding to sound) onto changes in another continuously varying quantity (e.g. an electrical voltage). Thus, the electrical signal created by a microphone is an "analog" of the sound it captures. Analog information can be communicated along cables or through space using radio waves by encoding it in variations of electrical properties (e.g. amplitudes, frequencies or phases). Similarly, analog information can be stored using, for example, the physical properties of a groove in an LP or magnetic variations on a tape. As a result, most analog transmission and storage systems are dedicated to one type of information or another. For example: AM/FM radio, telephones, LP records and audio cassettes for audio, TV and video cassettes for video, and books and magazines for text and pictures. The ways in which analog information is encoded in electrical signals is tightly coupled to the capabilities of the analog electronics in transmitters and receivers. Similarly, the way analog information is stored is tightly coupled to the electrical, magnetic, chemical, or physical characteristics of the underlying materials. Limitations of analog electronics mean that the values of the electrical components in the circuitry have to be selected during design to match a particular signal or storage format. This results in extremely tight coupling between devices and transmission/storage formats. Industries built around these technologies in the early part of the 20th century (e.g. broadcasting, telephony, and music distribution) had their own technical standards to ensure interoperability within their own

computing on systems development [18], distributed co-developers [19], or non-market peer software creation [20, 21], [22].

² Please see [24] for a fuller history with a richer set of references.

infrastructures. These industries and technologies remained in stable configurations for decades. The separation of the devices and formats in each industry constrained the connections that could be made between them and formed a major barrier to inter-industry competition.

The vertically integrated and tightly coupled technologies (e.g. telegraphy, telephony, radio, and TV) relied on high fixed-cost infrastructures [3]. The mass market required to provide an economic return on these technologies had the side-effect of concentrating the production of information products in the hands of the few. The resulting *producer-consumer paradigm* involved relatively few producers programming for a mass audience. But it did not, or could not, attend to diverse small audiences. Thus, control of the physical infrastructure (i.e. printing presses, spectrum, and networks) gave a small number of owners and publishers control over the flow of information and of who got access to large audiences. Authors, musicians, playwrights, and other content producers had to persuade gatekeepers (e.g. publishers, record labels, TV Networks, film studios, editors, etc.) that their work was worthy of distribution. This power was regulated by governments in various ways (e.g. through state owned telecommunications or broadcasting) but in doing so bolstered the institutionalization of the producer-consumer paradigm. The configuration of telecom industries similarly constrained innovation since no one could legally attach anything to the network without permission. While details varied by geography we can conclude that the nature of analog technological infrastructures kept distinct industries largely separate. In addition, high fixed-costs favored industry concentration, the producer-consumer paradigm, and a strong regulatory hand. These elements were interlinked within the web of social and competitive behaviors, and shaped the service and content offerings of the telecom and media industries that endured for much of the 20th century.

2.2 The digital turn

Digitizing refers to a process whereby analog signals come to be represented by numbers, and ultimately as bits (a contraction of **binary digits**). Any analog signal can be digitized including audio, video, and images of increasing resolution and quality. The flexibility of digitizing is that, in principle, the same storage, transmission, and processing technologies can store, transmit, or manipulate just about any type of digital information. Thus, various forms of digitized information no longer have to be tightly coupled to particular

transmission and storage technologies. Digitizing has the potential to dissolve the boundaries between industries hitherto kept apart and to change the underlying economics of information distribution (e.g. high fixed distribution costs can be shared across services). Orders of magnitude increases in the digital transmission and storage capabilities have made sending and storing multiple types of information over the same networks and storage media both technologically possible and economically feasible.

We make a distinction between *digitizing* and *digitization*. *Digitizing* connotes a technical process of representing diverse types of information in digital form. *Digitization*, in contrast, refers to the socio-technical process of applying such techniques across industries and contexts in ways that affect and shape their underlying infrastructures for the creation, storage, and distribution of content, applications, and services. Examples include the digitization of the telecom infrastructure (started in the 1970s and took decades), broadcast TV (started in the 1990s), and book publishing (still in its early stages).

Typically, the first wave of industry *digitizations* did not unleash the full potential of *digitizing* to breakdown industry walls. Not surprisingly, the digitization of telecom networks built upon the architectures of the analog infrastructure – after all the new digital elements had to interoperate with the analog ones during the transition. The social and institutional environment inherited from the analog era was just as important. For example, engineers and managers had their expertise and business processes anchored in analog telephony and its associated technologies, interfaces, and architectures. Telecommunications regulation also limited the rate at which new configurations could be established. Similarly, the first waves of digitization in cellular radio (1G to 2G), music (vinyl to CDs), and more recently the transition to digital TV were not immediate catalysts for breaking down the social and institutional environments. The digitization of key elements in established infrastructures did, of course, lower costs and improve the quality of industry offerings. In the early phases of digitization change could be characterized as expanding the market and creating “more of the same” sorts of connections e.g. increasing telephone penetration and call volume. This can be thought of as the digital equivalent of “paving the cow paths.” Because of this industries built around telephony, broadcasting and other forms of content distribution were not able to encroach on one another. Even by the mid-1990s the dominant digital devices (e.g. CD players, set-top boxes, mobile phones) were single purpose devices, and

remained tightly coupled to the infrastructures of single industries.

Despite widespread digitization during the latter part of the 20th century the inherent flexibility of digitizing was not widely realized until two elements reached critical levels: (1) the ubiquity of small and powerful digital computers, and (2) the ubiquity of connecting those computers through a neutral and “general purpose” digital transmission infrastructure.

(1) The ubiquity of the digital computer broke the tight coupling between analog and digital electronics dedicated to processing just one signal format built for a single purpose. The programmability of the digital computer was ideally suited to manipulating bits representing *any* digitized information. The software that controls it provides nearly unlimited flexibility in information manipulation. Technical standards and new architectures created constraints on the limitless variability of digitizing that could have otherwise induced unmanageable heterogeneity. Exponential increases in processing power, data storage, and bandwidth meant that ever-richer content could be supported. Digital computing and the malleability of software made possible a *device convergence*, where a digital device became capable of storing, processing, and communicating, multiple types and formats of digitized information. The popularization of the smart-phone serves as an example of this development.

(2) The other key element to unleashing the flexibility of digitizing was the rise of packet switching and of the Internet Protocol (IP) in particular. IP provides *upward flexibility* for the creation of any application or service that can use its simple communications capabilities – without having to get the permission of the network operators. It also provides *downward flexibility* in that a wide range of physical networks and behaviors with diverse characteristics can be used to provide fully compatible connectivity. IP thus helped break the tight coupling between services or applications and the underlying network [25]. This facilitated *network convergence* where all types of digitized information can now be communicated and distributed on the same infrastructure. Hence, the Internet became *the* platform for the development and delivery of just about any information-based application, or service.

Software-defined digital devices and IP based networks do not have specific behaviors and relationships as deeply inscribed into them as their analog and early digital predecessors. In the late-1990s the inherent flexibility of digitizing combined with the malleability of software, and increasing capabilities of digital processing, storage, and IP

based communications reached a *tipping point* [26]. The tight couplings among services, devices, and content distribution networks were shattered and the mutual dependencies between stable industry structures and technical infrastructures broken. The loosened couplings between devices, networks, and types of information unleashed enormous flexibility and disruptive potential. New and heretofore unimagined connections across the telecom, media, and computing industries continue to blur the boundaries between them. At the same time the producer-consumer paradigm came under increasing attack, for example, with global communities of consumers producing, discussing, assessing, and re-mixing media content [27, 28].

The fundamentally distinct characteristics of digitizing have now brought new visions for expanding services that could be provided on many physical networks and devices. Industry change was now characterized by the creation of new types of connections among actors of different sorts, not simply creating “more of the same” sorts of connections. So, as well as underpinning the phenomena of network and device convergence digitization also enabled a *divergence* in the sorts and the patterns of connections. Digitization was now moving beyond paving of the cow paths to the building of a new highway system. The increased flexibility quickly brought turmoil to music distribution and chemical photography. More recently video distribution and newspapers have suffered. Customers and business models have disappeared quickly as new ways of creating and delivering services sprung up. All manners of interactive information (e.g. Wikipedia), entertainment (e.g. YouTube), gaming (e.g. World of Warcraft), communication (e.g. Twitter), and other services were now deployed on any copper pair, coax, fiber, or radio based networks. Linked to new breeds of enterprise wide infrastructures (built around ERP/CRM systems and databases) radically new business models were invented e.g. Amazon, eBay, Google, and Netflix.

This brief overview of the digital turn highlights the critical role of the *flexibility* afforded by digitizing in shaping the information storage and transmission infrastructures. Consequent radical changes in social and institutional orders can be thought of as *market or industry convergence* in the sense of allowing interconnection of previously separate industries combined with a *market or industry divergence* in which all manner of new connections and applications become feasible. The stable interlocking of analog infrastructures and industry structures has been replaced by new

dynamic dependencies and related trajectories among co-evolving digital infrastructures and new forms of social and institutional order. A variety of views have sought to describe these dynamics under the heading of “digital convergence.” These are discussed next.

3. Conceptualizing digital convergence

3.1 Review of the debates around digitization

Most early conceptions of *digital convergence* in the practitioner literature were concerned with “the ability of different network platforms to carry essentially similar kinds of services” and of “the coming together of consumer devices such as the telephone, the TV, and the personal computer [2].” Such perspectives echo the ideas of *network and device convergence* (§2). Similarly, convergence has denoted the sharing of resources (e.g. spectrum, bandwidth, battery power, etc.) for different applications [29]. Consequently, consumer electronics manufacturers explored a range of functionalities that could be incorporated into home server convergence devices [30] and mobile phones came to support multiple networks (e.g. GSM/UMTS, Wi-Fi, DVB-H, GPS, and Bluetooth) and all sorts of entertainment and computing functions [5].

Network and device convergence in turn has permitted alternative network platforms to carry a wider range of services. The resulting *market convergence* [6] meant that telecom, cable TV, and satellite network operators offered similar services (e.g. triple play bundles of TV, phone, and Internet access) and competed with each other. Similarly, desktop and mobile computing and communications devices incorporate audio, image, and video processing capabilities that have redefined, or are redefining, distribution in many industries (e.g. photography, TV, and music distribution). Thus, the *convergence* of underlying network and device technologies resulted in major changes in the structures and boundaries of practically all communications and media industries. Industry level changes were reflected in changes in the composition of industry level alliances [31], in increases in the interrelatedness of intellectual property patented across industries [32], and in growing horizontalization of the mobile business [33].

As new digital technologies, particularly the Internet, became infrastructural the changes in social arrangements went beyond redrawing industry boundaries. Digitization’s effects became pervasive and heterogeneous in contrast to earlier local changes equivalent to ‘paving the cow paths.’ Finally, the

inherent flexibility of digitizing information was realized as separate streams of digitization merged, and platforms and devices came to support heterogeneous applications and content. Merging of historically separate socio-technical infrastructures and increasing infrastructural momentum are at the heart of the search for the meaning of digital convergence. It has transformed how nearly all significant information products are produced (e.g. peer and social production forms), and has been a major challenge for regulatory regimes [34].

Digitizing has exacerbated one of the distinguishing features of information products: while information is costly to produce, it is cheap to reproduce. Economics-based views of digitization have focused on the strategic implications of changes in content distribution for large companies [e.g. 35]. However, a full examination must also take into account the changes in the production networks as well as distribution. The Internet and cheap personal computers now allow individuals and small groups to produce their own products that can be distributed for next to no cost to audiences both large and small. Low distribution and search costs allow a “long tail” of niche interests ignored by mass media to be catered [36]. The Internet has also provided a platform for individuals and small groups to work with one another, enter into discourses, create their own content, interact with and repurpose mass media content [7], or innovate in ways not facilitated by mass media [37]. In many cases these activities are not organized under hierarchies or by markets but along networks [37]. However, it is not just the Internet’s cost structure that brought about these changes. The Internet Protocol’s (IP) technological architecture makes no assumptions about the sorts of services it is to be used for. IP simply makes a best effort attempt to deliver packets from one device to another [38]. This open architecture along with the availability of free software provided the “new” commons for the creation and distribution of content. There is no center of control and neither application designers nor content producers need ask for permission to make use of the infrastructure. An alternative for the creation and distribution of information, let’s call it the *digitally networked paradigm*, is enabled by the nature of the protocols and the lower fixed-costs required to participate. As with the infrastructures developed in the early 20th century the nature and economics of digital infrastructures enable certain interactions and shape what is economically feasible. The most frequently cited products of the digitally networked paradigm include open-source software (e.g. Linux and Apache), collaboratively created references (e.g.

Wikipedia), individual and collective publications and evaluations (e.g. blogs), and the sharing of distributed processing power (e.g. SETI@Home). Thus a primarily technological convergence, around IP, supported a socio-technical divergence in means of creation and distribution of content, applications, and services.

At the same time network and terminal convergence has brought wider regulatory and policy implications, e.g. the creation of a new regulator in the UK to oversee *both* telecom and broadcasting [34]. More generally, the actual changes in industries and the ways in which new information products are created and mediated by the regulatory environments which are themselves strongly influenced by the lobbying by proponents of the producer-consumer paradigm and increasingly by supporters of the digitally networked paradigm [39].

Recently a number of authors have analyzed aspects of change in digital technologies. Adomavicius et al. [40] use an ecosystem metaphor to develop an approach for making sense of change in IT products. They formulate a hierarchical model consisting of *products and applications*, comprised of *components*, which are supported by (technical) *infrastructure*. Interactions among elements at each level form the dynamic relationships of an ecosystem (e.g. the development of the DVD *product* spurred development of enhanced DVD *component* technologies). Their idea of decomposing technical complexity around how information is *digitized*, stored, processed, and transmitted is potentially valuable in understanding how small changes in components can have major impacts at other levels of the hierarchy. However, by excluding consideration of the institutional and the social the approach can only be of limited use in helping to understand the essentially the *socio-technical* nature of *digitization*.

Funk [41, 42] goes further by modeling technological change as the interplay between customer choice and product design hierarchies. Design trade-offs and customer requirements implicitly entail social considerations. Improvements in low level components change design trade-offs at higher levels of the hierarchy (e.g. the various sub-systems of a PC). Major technological discontinuities can be conceptualized as the result of such changes impacting design trade-offs at the overall system, or product level. The cascading effects of such changes can be seen to alter the trade-offs of how firms use IT within a nested hierarchy of sub-systems [43]. While this is an improvement over a purely technical explanation it does not explain industry level changes, or broader reconfigurations of social

arrangements associated with increasingly pervasive waves of digitization.

Adomavicius et al. [40] and Funk [41, 42] offer a way breaking up the socio-technological world that helps us examine the dynamics therein. However, their bias towards the technical and the lack of consideration of infrastructures make their perspectives less suitable for examining the socio-technical phenomena of digital convergence (and divergence). An alternative is discussed next.

3.2 Defining digital convergence (divergence)

Having considered several perspectives on the digitizing and digitalization we can next propose a set of criteria that any framework that purports to explain digital convergence/divergence would have to satisfy.

1. *Account for the expansion and growing complexity of technological infrastructures*
2. *Account for the dynamic mutual dependencies among social and technical infrastructures*
3. *Provide some way of breaking up an increasingly interconnected socio-technological world into separate domains that allow meaningful study*
4. *Use the domains outlined in (3) to explain at least some of the most important dynamic mutual dependencies referred to in (2)*

For the rest of this section we draw upon a perspective developed by legal scholars [1, 3, 44]. One reason is that this approach adopts a universal infrastructural viewpoint and recognizes the mutual dependence of social structures and the technical world. Benkler [44] and Lessig [3] propose a three layer model to discuss how the potential for wider creativity to be unleashed by the Internet may be tempered by the ways in which incumbent media giants can exert control of the creation and the distribution of content. In this model the *physical layer infrastructure* includes the networks of cables, computing hardware, and radio frequency spectrum. Non-digital physical layer infrastructures include books and magazines, LPs and CDs, video tape and film stock. It can also refer to physical locations for performances (e.g. theatres, and speakers' corner).

The *logical infrastructure (or code) layer* is the logic that drives the physical infrastructure. In communications networks this corresponds to the software that makes the hardware run e.g. data protocols, the software that implements them, as well as services logics embedded in phone networks. For non-digital physical infrastructures the corresponding logical infrastructure could be the social protocols for

getting published, signed to a label, or other ways of persuading gatekeepers to distribute creative works.

The *content layer* represents what is sent across the infrastructure e.g. images, text, speech, music, or movies. This layer also has its own infrastructures. For example, intellectual property laws define what content is owned and what is left to the commons.

Lessig [3] argues that media exhibit differing patterns of openness at each layer. See Table 1 for examples from the telecom and media industries. Resources are considered free and open if people can them without permission or if the permission is granted neutrally. From this perspective it is the open architecture (any type of connectivity) of the Internet at the code layer and the availability of high-quality free software from the open source community at the content layer that provided the commons where new applications and means of producing information products could be tried. The non-market, decentralized, distributed peer production phenomena coordinated in loose informal networks developed GNU/Linux, Apache, and other open source software as well as Wikipedia, YouTube, elaborate fan fiction, wikis, and other user-created content [7, 27].

Having discussed some effects of the digital infrastructures on the social arrangements of information production we now explore examples of social actions and infrastructures shaping technical infrastructures. Lessig and Benkler [3, 44] argue that regulatory or policy action at the code and content layers are re-establishing central control points that can be used by the incumbents to perpetuate the producer-consumer paradigm (e.g. the duration of copyright protection has been extended repeatedly and its scope expanded until it encroaches on the fair use of information products in public discourse). While strong intellectual property laws encourage content creation by allowing the author to benefit financially (higher revenues) they also impede content creation building on what went before (higher licensing costs and having to seek permission). Strong intellectual property laws tend to reinforce the producer-consumer paradigm, as less of the culture’s information products are available in the commons as source material for new content.

Content creators participating in peer production select what they will work on and in many cases seek intrinsic as opposed to extrinsic (monetary) rewards [1]. This mode of production relies on a commons of information products that can used as input for the creation of new ones and is therefore constrained by strong property rights that restrict the reuse and reconfiguration of much of the existing stock of information products. Lessig [3] argues that the role of government is critical in striking the balance

between these conflicting forces, but that incumbents from the centralized, hierarchical, market-based configurations have lobbied hard to stack the deck against new modes of information production.

Table 1. Examples of open and closed configurations at each layer

	Closed / Controlled	Free / Open
Content	Patented inventions, proprietary software, and copyrighted works, sponsored standards (e.g. MP3), and DRM.	Works in public domain, released under the creative commons, open source software and some standards
Logical infrastruct (or code)	Service logic embedded in phone network (intelligent network architecture). Only phone company could deploy new services.	The Internet has “end-to-end” architecture with intelligence retained in end devices. ‘Dumb’ IP network concerns itself solely with packet routing.
Physical infrastructure	Wired networks are rivalrous & capital intensive. Innovation limited to owner. Govt monopoly in allocating spectrum gives incumbents advantage over innovators needing spectrum.	Regulation of monopoly phone networks permitted their used for Internet access. Unlicensed spectrum provided commons for development of Wi-Fi and Bluetooth.

Bowker and Star [12] argued that standardized and widespread classifications become part of the infrastructure and in doing so fade into the background. This is exemplified by the rigid structures for interactions between content producers and the gatekeepers of the TV, radio, newspaper, and book publishing industries that endured for most of the 20th century. As the ways of creating and distributing content were standardized they became institutionalized and in turn shaped the ways in which people interacted. Thus, the content layer also has deep infrastructural elements such as the regulations, policies, rules, laws, and norms that define and constrain interactions within the industries examined.

At the code layer the Digital Millennium Copyright Act (DCMA) criminalizes circumvention of digital rights management mechanisms used to protect copyrighted material. While these measures reinforce copyright protection they also restrict the reuse of information critical for the creation of new information products that would otherwise have been covered by “fair use” in the US legal system. Thus the DCMA further bolsters the producer-consumer paradigm. There has also been controversy at the physical infrastructure layer. “Network neutrality” refers to the idea that owners of physical network infrastructure should not “discriminate against some packets while favoring others [3].” Its proponents argue that it is necessary to maintain the Internet’s

end-to-end principle [45] and that the network should remain “dumb [46].” Opponents counter that such legislation inhibits investment and hinders innovation to support improved service quality and security [47]. Thus strategic action not only affects the content layer but also the code (e.g. DCMA) and the physical layers (e.g. net neutrality). Thus, the social does not sit atop the stack but is embedded at all layers.

While simple one sentence definitions would suffice for *device, network, or market* convergence they would fail to do justice to the richness of the digital convergence (and divergence) phenomena that underpin the diversity and scope of technical and social change during the last two decades. To this end we put forward a rough working definition of digital convergence that builds on the three layer model.

The essence of *digital convergence (and divergence)* is represented by the dynamic interactions among four sets of mutually interdependent elements:

1. *The interconnection, overlapping, contention, and reconfiguration of physical and logical socio-technical infrastructures,*
2. *The reconfiguration of organizational and group interconnections brought about by changes in the physical and logic infrastructures,*
3. *Changes in the ways that new content, applications, and services are created, and*
4. *The changing locus of innovation driven by countervailing forces widening (e.g. platforms for open source collaboration) and constricting (e.g. increasing reach of intellectual property laws) the means of information creation and distribution.*

This layer model allows us to develop dynamic socio-technical explanations to understand not just incremental change but also the dramatic episodes of change that blur industry boundaries and change other social arrangements, as well as resulting in technological change (e.g. differing facets of digital convergence and divergence). Examples of the changes at one layer impacting the other layers are provided in Table 2.

While the layers can be stable for long periods (e.g. socio-technical infrastructures built around analog technologies) gradual changes in one layer impact others and occasionally reach an inflection point that brings about radical change (e.g. unleashing of digital flexibility). These sorts of non-linear interactions across layers can lead to punctuated equilibria in the Gouldian meaning with the recursive nature of the layers (or hierarchies) providing the sources of mutation and ‘natural’ selection needed for evolution within and across the

socio-technical ecologies. In this sense the three-layer model extends Adomavicius et al. [40] model as a socio-technical ecology. Next we discuss options for the IS field to increase its understanding of the infrastructures which are fundamental to understanding information systems.

Table 2. Examples of cross layer impact

	Physical	Logical (or Code)	Content
Content	New applications (e.g. www) provide incentives for faster networks, more capable devices, and improved component technologies	<ul style="list-style-type: none"> • New creative opportunities drive creation of new logical infra (e.g. Web 2.0) • Rapid change driven by upward/ downward flexibility between code/content layers 	<ul style="list-style-type: none"> • Cultural and other information products used as basis for new creative works • Strong intellectual property laws double edged sword for content creators
Logical (or Code)	<ul style="list-style-type: none"> • Controlled logical infra limits innovation to owner • Open logical infra (e.g. IP) incentivizes development of faster networks to support widest range of applications. <i>Downward flexibility</i> 	<ul style="list-style-type: none"> • Controlled logical infra (e.g. telephony) has a coordinated tech migration path • Open logical infra allows “a thousand flowers to bloom” i.e. anyone can create a protocol 	<ul style="list-style-type: none"> • Highly integrated logical infra provides optimized platform for restricted few services but restricts innovation • Reverse true for logical infra with few assumptions about services (loose coupling). ‘Upward’ flexibility.
Physical	<ul style="list-style-type: none"> • Improved performance in one area gives incentives for development of others <ul style="list-style-type: none"> - Competition among device, network, processing, and storage technologies - Faster networks drive need for processing & storage improvements • Size, perf., cost improvements facilitate <i>device convergence</i> 	<ul style="list-style-type: none"> • Existing or imagined physical infra required for development of logical infra • Inflexible standard ties logical infra tightly to physical layer (e.g. analog TV) • Flexible standard decouples physical and logical infras and supports network and <i>market convergence</i> (e.g. triple play) 	<ul style="list-style-type: none"> • Cheaper, faster physical infra <ul style="list-style-type: none"> • Bandwidth/ processing intensive apps become viable (e.g. VoIP, video conf.) • Richer media for content creators • Broadcast services on unicast networks • Lowers prices fuels demand

4. Discussion and research implications

The IS field’s research focus has clearly been at the top of the ‘stack’ and has tended to take the characteristics for underlying infrastructures for granted [12]. This comes as no surprise as individual systems and technologies have often faded into the background [23]. However, the examination of the evolution of the telecom and media industries illustrates the crucial role that the characteristics of both the social and technical infrastructures have on the services and applications and on the connections between industries. There is no reason to believe that the waves of digitization are finished. What we have witnessed to date may well be just the early phases. Cloud computing, web services, and related approaches will result in infrastructures operating at higher layers of the stack than current networking

protocols, or operating systems. These new infrastructures could again be catalysts for radical changes in the ways that individuals, groups, and organizations interact, coordinate, produce, and consume. The digital intertwining of industries and infrastructures will likely continue as visions of optimizing transportation systems, streamlining healthcare, and managing energy usage and generation using real-time information on supply and demand, emerge as realities built upon digital communication and computing infrastructures. New infrastructures as well as industries will undoubtedly experience on-going digital convergence (and divergence).

In the short term IS researchers can initiate the study of infrastructural topics by re-examining the interrelationships between what we know from existing IS research categories and the then existing logical and physical infrastructures. This could provide a knowledge base characterizing the role of diverse infrastructure characteristics. It also holds out the possibility of being able to map the connections among disparate prior findings by explicitly incorporating the role of these characteristics.

At the physical infrastructure layer these characteristics will include dimensions like bandwidth, quality of service, latency, ubiquity, mobility, mode (e.g. broadcast, narrowcast, of interactive), radio frequency, power requirements, and sharing techniques. Social dimensions will revolve around investment incentives, control of access to connections or spectrum, regulatory frameworks, and actions of other institutional actors.

At the logical infrastructure layer pertinent characteristics may include the properties of communications protocols, services, and technical architectures. The social dimension will include architecture and access controls, and institutionalized ways of doing (or not doing) things. Some characteristics will be scalars while others will be represented by their presence or absence (e.g. presence or absence of intelligence in the network). The relevant characteristics of an ever widening range of converging infrastructures and related industries (e.g. energy, transport, and medical) will add to the richness in all layers.

Longer term the challenge for the IS field is to build deep understandings of the dynamics of the socio-technical relationships across the layers of infrastructure and the related socio-technical phenomena that have traditionally been at the center of the field's concerns. Conceptually, this can be thought of series of matrices (each like the one depicted in Table 2) that map out the changing relationships over time.

Examining the role of information infrastructures is timely for the IS field as understanding how the layered infrastructures interact and what roles abstractions and flexible couplings play will become even more central in studying information systems. Tackling this startling gap in the IS literature would also help the field heed earlier calls to take the details of industries seriously [48] and to focus on high-visibility, high-impact research [49]. It also holds promise for helping practitioners navigating the uncertain waters of on-going digitization.

6. References

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