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The Internet of Things (IoT): A Research Agenda for Information Systems

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Abstract:

The Internet of things (IoT) is emerging as an integrated set of digital innovations with the potential to unleash unprecedented opportunities and create significant challenges from both technological and societal perspectives. The IoT's emergence signals many valuable opportunities (particularly for information systems (IS) scholars) to conduct scholarly inquiries. We posit that, since the IS discipline operates at the intersection of information technologies' (IT) social, business, and technical aspects, IS scholars have a unique capacity to understand and contribute to advancing research on this new topic and associated phenomena. We outline the IoT's distinctive attributes and their implications for existing IS research traditions. Furthermore, we highlight some illustrative research perspectives from which IS scholars can study the IoT. We highlight a research agenda for IS in two different ways. First, we discuss four IS characteristics that change based on IoT elements: 1) the physio-digital continuum, 2) multi-level exploration of IS, 3) composite affordance, and 4) heterogeneity. Second, we discuss the ways in which the IoT opens up research opportunities based on its impact on four major thematic domains: 1) organizations, 2), technology, 3) individuals, and 4) society.

Keywords: Internet of Things, Research Agenda, Digital Innovations, IS Impact.

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1 Introduction

The Internet of things (IoT) concept has gained widespread use and attention among practitioners and in the trade press. However, despite the industry's growth, academic research has not focused on the IoT and IoT-related phenomena as intensively. We believe that the information systems (IS) discipline has a unique capacity to contribute meaningfully to this emerging area from various perspectives (Baiyere, Venkatesh, Donnellan, Tabet, & Topi, 2016) given that the discipline operates at the intersection of information technologies' (IT) social, business, and technical aspects (Baskerville, Baiyere, Gregor, Hevner, & Rossi, 2018; Benbasat & Zmud, 2003; King & Lyytinen, 2006). To this end, we present a research agenda on potential research directions to examine the IoT.

Scholars and practitioners have conceptualized the IoT in different ways (Atzori, Iera, & Morabito, 2010; Chui, Löffler, & Roberts, 2016; International Telecommunication Union, 2005; Miorandi, Sicari, De Pellegrini, & Chlamtac, 2012). However, these conceptualizations share shared elements on which we base how we conceptualize the IoT in this paper. We define the IoT as a system of interconnections between digital technologies and physical objects that enable such (traditionally mundane) objects to exhibit computing properties and interact with one another with or without human intervention. Here, digital technologies can refer to software, sensors, electronics, actuators, digital identifiers, networks, and so on. Physical objects refer to the traditional "things" in the IoT, which can refer to any man-made or living objects with the potential to exhibit some digital capabilities such as sensing, data capturing, and/or communication. The IoT captures the accelerated interconnection between the electronic domain and the physical domain—which we can express simply as the expanding point at which bits and atoms meet (Ishii & Ullmer, 1997; Mitchell, 1996). With this overarching scale, the IoT may arguably touch (almost) every type of human endeavor, which includes energy, healthcare, manufacturing, agriculture, transportation, retail, education, and government (Kees, Oberländer, Röglinger, & Rosemann, 2015; Miorandi et al., 2012; Whitmore, Agarwal, & Da Xu, 2015). Indeed, since the IoT can address a broad range of societal, technological, and business opportunities/challenges (Shim et al., 2019), both scholars and practitioners need to pay attention to its impact and the possibilities it creates.

IoT system implementations can include traditional objects that built-on IoT capabilities augment and/or objects that have built-in IoT capabilities, which makes them smart objects. In contrast to traditional objects, these enhanced devices pass digital interactions and feedback/data throughout a process and between process infrastructure, user feedback, and each other. Traditional objects, however, can pass only manual interactions and feedback (see Figure 1). As users pursue an end goal, they follow a process that traditional information systems enable. With IoT systems, users, objects, and processes can pass information to one another to enable a desired goal.

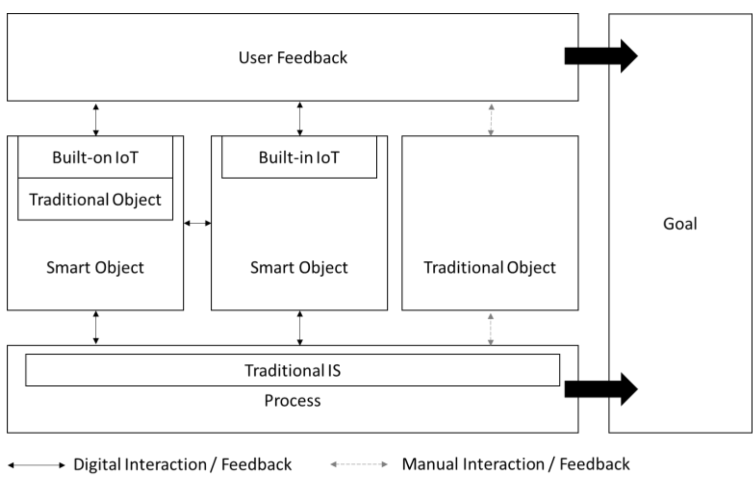

Figure 1. The Relationship between Smart Objects, Traditional Objects, and Traditional IS in an IoT System

Despite the significant impact that many researchers and practitioners have predicted the IoT will have, researchers have not sufficiently studied and, thus, not fully established its full potential and utility. Among other research possibilities, the IS community has an opportunity to play a pivotal role in identifying, outlining, and stimulating new and unique application areas for IoT and in mapping out the IoT's associated implications for both business and society. In addition, the IoT presents critical ethical, legal, and policy dilemmas. The breadth and depth with which the IoT affects individual lives, business activities, and societal policies also creates possibilities for various actors to abuse and misuse the IoT (Dlodlo, Foko, Mvelase, & Mathaba, 2012; Sicari, Rizzardi, Grieco, & Coen-Porisini, 2015; Whitmore et al., 2015; Da Xu, He, & Li, 2014; Zuboff, 2015, 2019). Key areas that scholars should examine include security issues, current technological limitations (Qin et al., 2016), and surveillance capitalism (Zuboff, 2015, 2019). As a practical example, we can identify such concerns in cases such as the case in which security researchers remotely hacked a Jeep Cherokee in 2014 while someone drove it (Greenberg, 2015; Pogue, 2015; Von Roessing, 2016) and the case in which researchers demonstrated that they could, among other things, hack into a Nest Learning Thermostat in a home, spy on its owner, take advantage of other devices on the network, and steal wireless network credentials (Hernandez, Arias, Buentello, & Jin, 2014). These devices' vulnerability and associated exploitation raises concerns about the harm that may befall both systems and the data that flows through them. These issues provide the motivation to search for ways to overcome these challenges and limit the IoT's negative consequences while realizing its positive potential (Shim et al., 2019). Both technical and social research engagements will likely contribute to solutions that address these highlighted issues.

From a historical perspective, we can see that, since telephones and automobiles in the previous century and computers and smartphones in recent times, technological advances typically have had both positive and negative consequences. Each successful technological wave has brought different changes that impact individuals, organizations, and society as a whole. Likewise, the IoT will possibly represent a successful wave (Li & Xu, 2015). However, it remains unclear whether the IoT phenomenon constitutes product of technology hype or an emerging technological wave that carries noteworthy significance. In this paper, we explore this question from practical and theoretical perspectives and propose a research agenda for scholarship in this direction for the IS discipline.

As we reflected on the IoT, its potential, and its implications for IS research, we realized that one can trace the IoT's genesis back to several constructs that prior IS research has actively studied. For example, some IS concepts relevant to the IoT include ubiquitous computing, Web of things, industrial Internet, physical Internet, smart cities, pervasive Internet, connected environments, situated computing, wireless sensor networks, and so on (Forman, Goldfarb, & Greenstein, 2005; Gholami, Watson, Molla, Hasan, & Bjørn-Andersen, 2016; Kohli & Grover, 2008; Lyytinen & Yoo, 2002a, 2002b; March, Hevner, & Ram, 2000; McCullough, 2004; Wolcott, Press, McHenry, Goodman, & Foster, 2001; Yoo, Henfridsson, & Lyytinen, 2010).

This paper proceeds as follows: in Section 2, we summarize the IoT's potential and challenges. In Section 3, we unpack four delineating characteristics that differentiate the IoT from regular objects, IT objects, and smart objects: 1) design purpose, 2) everyware, 3) data lifeline, and 4) connectivity. Subsequently, we justify why the IoT holds potential as a relevant and important topic for the IS discipline to study. To do so, we outline the IoT's potential unresolved challenges that represent opportunities for scholarly inquiry from two different perspectives. In Section 4, we use these IoT characterizations as a locus for presenting conceptual implications to conduct and think about future research around IoT in the IS discipline. In Section 5, we outline an illustrative research agenda around three impact domains. Finally, in Section 6, we summarize key research agenda items and conclude the paper. We outline overall structure we follow in this paper in Figure 2.

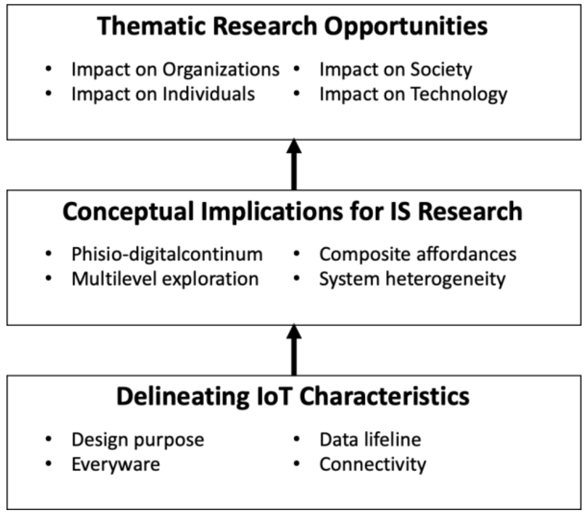

Figure 2. Towards an IoT Research Agenda in IS

2 Scholarship Opportunities: IoT Potential and Challenges

IoT technologies and solutions have arrived and will likely keep growing. Researchers have predicted that, in the near future, seven billion people and businesses will connect to the Internet compared to more than 35 billion connected things (Lopez, 2016), which includes 250 million cars (Velosa, Hines, LeHong, Perkins, & Satish, 2014) and even connected animals (Tratz-Ryan, Jones, Ingelbrecht, & Escherich, 2014). All this information will create hundreds of zettabytes of data (Turner, Gantz, Reinsel, & Minton, 2014) that could add US$2 trillion to the world economy (Burton, Burke, & Blosch, 2016). Although IoT technologies and solutions present massive opportunities, we will need to address significant technical, policy, and social challenges. Furthermore, many people have talked about the IoT as the next industrial revolution. However, we already live in a world where the number of connected devices exceeds the number of people on the planet. Far beyond the smart thermostat in our homes, IoT applications that connect the physical world to the digital realm continue to spread across industries. IoT applications save lives with wearable medical devices that monitor patients' vital metrics. They improve air quality by managing emissions from factories and cars. Organizations now monitor their supply chains in real time from the cradle to the grave. These IoT characteristics and outcomes raise myriad research avenues to understand the IoT's social, business, and technical components.

The fact that technical developments have made it possible to make more intelligent small and large physical objects that can communicate with their environment about their status and behavior and send and receive control instructions does not alone constitute enough justification to create an interesting research area. Many IoT applications require seamless interconnectivity and integration between the physical and digital realms and the ability to process vast quantities of heterogeneous data created at very rapid speeds. However, these two facts together still do not constitute enough reason to create a new research area. We need to go beyond the practical potential to an engagement that generates insights that offer theoretical and practical value. When considering a research agenda for the IoT in IS, we need to first think about fundamental assumptions regarding the relationship between the IS discipline and the IoT (especially given the IoT's multidimensional nature).

First, over the IS discipline's relatively short history, IS scholars have positioned the discipline as a multi-faceted discipline that looks at the intersection of information technologies' (IT) social, business, and technical aspects. IS journals have published many good papers that classify the IS discipline as one that publishes research from multiple perspectives. To use two recent examples, Abbasi, Sarker, and Chiang (2016) specified three IS research traditions: behavior, design, and economics of IS. Sidorova, Evangelopoulos, Valacich, and Ramakrishnan (2008) identified five core IS research areas: IT and organizations, IS development, IT and individuals, IT and markets, and IT and groups (and essentially provide evidence regarding the importance of the association between technology and four different levels of human activity in IS research). Using just these two frameworks as examples, we can see that the importance of such frameworks when systematically exploring opportunities for scholarly work related to a new phenomenon. How does work on the IoT fit with the social, business, and technical IS research traditions? To what extent does the IoT pertain to the levels of analysis that Sidorova et al. (2008) identified (i.e., individuals, groups, organizations, and markets/societies)?

Second, the IS discipline focuses more on what implications IT has on organizations and individuals, how IT transforms human activity, how actors use IT, and how actors generate value from IT than on IT itself. The IS discipline emphasizes questions that address IT's impact and transformational power on goal-driven, purposeful human activity at individual, group, organizational, or societal levels. Data, information, systems, and/or technology alone have little value if we do not attempt to understand them in a context that considers why one applied them. Research efforts related to the IoT should include this contextual understanding as an integral aspect.

Third, we should recognize that our discipline will likely not represent the best discipline to examine many essential questions related to IoT technologies. In examining the IoT, we should focus on finding our own distinctive perspectives and scholarly contributions rather than on examining questions and challenges that do not fit our discipline's scholarly agendas. We should explicitly acknowledge that some areas related to the IoT (which includes key elements of its technological foundations) will fall outside our focus and that we will need to rely on others' work to fully understand the phenomenon. We should be prepared to expand our horizon as we embrace the new frontiers of scholarly inquiries that the IoT provides but acknowledge the areas in which we need to collaborate with scholars from other disciplines.

Fourth, we should not ignore the links between the IoT and other currently relevant IS phenomena. The IS community continues to build bodies of work on, for example, big data (Abbasi et al., 2016), digital infrastructure (Tilson, Lyytinen, & Sørensen, 2010), digital innovation (Yoo et al., 2010)), healthcare (Fichman, Kohli, & Krishnan, 2011), and others (Baiyere et al., 2016). We believe that much knowledge the IS discipline has accumulated will remain highly relevant for scholarly work on the IoT. However, although we can gain value from drawing on our foundational theories, we should avoid wielding our prior theories as hammers and treating the IoT as yet another nail. Nonetheless, we should consider drawing from our current research streams as possible models for organizing and understanding the IoT phenomenon.

3 Delineating IoT Characteristics

In general, using the IoT as an opportunity to move future the IS discipline's boundaries beyond its current boundaries does not suggest that IoT systems totally differ from other IT systems. On the contrary, the IoT provides a foundation for new types of IS that draw on prior knowledge and principles about both IS and ITIT. Rather than debating the IoT's distinctiveness as a new field of inquiry, we consider it more relevant and useful to talk about how the IoT encourages researchers to expand IS research's horizons. Accordingly, we highlight four delineating IoT characteristics to articulate how we can distinguish IoT systems from other systems. In doing so, we shift the focus away from a static question ("what is the IoT"?) to a dynamic one ("when is the IoT?"). That is, we shift the focus to what characteristics need to exist at a particular point in time and what capabilities the interacting elements need to bring to a whole system for one to consider the system an IoT and the elements IoT components?

We draw our position's premise from Star and Ruhleder's (1996) "when is an infrastructure" and Engeström's (1990) "when is a tool" ideologies, which we consider relevant in unpacking the IoT as a dynamic phenomenon. Thus, rather than engaging with the "what is IoT" question, we focus on unpacking the IoT based on these perspectives. We conceptualize the IoT not as a thing with preset attributes frozen in time but as a system in practice, an ensemble of things in a context and in connection to some particular activity. This view suggests that an object can exist either as a component in an IoT system or independently. The "when is the IoT" conceptualization explicitly recognizes that the IoT's existence depends on interactions between its components—without this interaction, one cannot consider components with IoT potential as the IoT. This view contrasts with prior views that consider the IoT a specific entity with a perpetual existence and IoT attributes (Atzori et al., 2010; Chui et al., 2016; Iera, Floerkemeier, Mitsugi, & Morabito, 2010; Miorandi et al., 2012). Although this view provides valuable foundations for understanding the IoT as a theory, such conceptions take for granted the IoT's connectivity. This connectivity better suits a perspective that views it as a system rather than an isolated device. Furthermore, viewing the IoT as a static thing limits one to consider an IoT object as *part* of an IoT system with little consideration that an object can *become* or *cease to be* a part of an IoT system.

Before we articulate the main ways in which we see IoT as expanding IS research's boundaries, we address some terminological nuances. The IoT as a whole refers to the entire network of interconnected nodes, whereas IoT technologies refer to the technical capabilities that enable one to construct IoT objects and such objects to function. We can regard IoT objects as unitary elements or "things" in an IoT context. IoT systems, in turn, refer to subsystems in the larger IoT that operate with a specific purpose and in specific settings, such as individual/home contexts, organizations, or society. With this background, we next present four characteristics that distinguish IoT systems/objects from other systems/objects: 1) design purpose, 2) everyware, 3) data lifeline, and 4) connectivity (see Table 1). The first two provide a delineation based on the "thingness" of IoT in contrast to IS, whereas the last two provide a delineation between the "Internetness" of IoT in contrast to ordinary things. However, note that we do not present these characteristics comprehensively representing what constitutes the IoT. Rather, we present them as parameters for delineating *when* an object constitutes a regular object, an IoT object, or an IS object.

Table 1. Delineating the IoT from Related Concepts

Delineating characteristic	Regular objects	IS objects	IoT objects
Design purpose: captures whether designers designed an object for computing, non-computing, or both computing and non-computing purposes. Useful for distinguishing between all three object classes (i.e., regular objects, IoT objects, and IS objects).	Primarily have a non-computing purpose (e.g., one primarily designs a chair for others to sit on).	Primarily have a computing purpose (e.g., one designs a computer for processing data and computing)	Combine both regular and IS objects' design purposes, which allows one to repurpose them (e.g., a smart watch has a different and more broad design purpose compared to a regular watch or the computing capabilities that enable a watch to become an IoT object).
Everyware: reflects an expansion in what qualifies as hardware in the computing sense from physical computing technologies to regular objects. Useful for distinguishing IS objects from IoT objects	Objects with the unexploited potential to serve as a conduit for computing (e.g., any traditional object, such as a chair).	Hardware or physical computing objects that have clear computing functionalities (e.g., printers, monitors, routers, etc.).	Extends the hardware concept from dedicated devices to include literally any object with computing and digital communication functionalities (e.g., a smart fridge, a smart shoe, a smart spoon).
Data lifeline: positions data as a fundamental necessity for any object to qualify for consideration as an IoT object. Useful for distinguishing regular objects from IoT and IS objects.	Lack data in fulfilling their design purpose (e.g., a chair does not need data to function).	Depend on data to fulfill their design purpose (e.g., a printer needs data to print).	Depends on data that they create and receive when fulfilling their design purpose (e.g., smart devices in general need data to operate).
Connectivity: emphasizes the need for objects to exist in connection to other objects in order to be part of an IoT system. Useful for distinguishing regular objects, IS objects, or (singular smart/ potential) IoT objects from other IoT objects in an IoT system.	Most regular objects lack the capacity to digitally connect and communicate with other objects (e.g., a dining table and chairs).	IS objects can possess the propensity to connect to other objects and communicate—a shared characteristic between IS and IoT objects that distinguishes them form regular objects (e.g., computers on a LAN network).	Besides possessing the other characteristics, IoT objects need to connect to other objects and be able to synchronously or asynchronously communicate beyond their own silo when fulfilling their design purpose (e.g., a personal assistant such as Siri, Alexa; a robotic arm in a connected factory, etc.).

3.1 The "Thingness" Delineation

3.1.1 Design Purpose

This characteristics refers to an object's innate purpose with regard to whether it has a primarily computing, non-computing, or both computing and non-computing purpose. IoT objects typically comprise regular objects with digital properties (Wiberg, 2018). Traditionally, people have designed objects with an intrinsic and distinctive purpose in mind. For example, people have historically designed chairs to serve an unmet need to sit down. With the IoT, one can digitize a chair and repurpose it for a wider range of options than what one would traditionally consider its initial purpose. Understanding an object's underlying design purpose serves as a qualifier to distinguish whether an object that possesses digital properties constitutes an IS object or an IoT object. Thus, design purpose distinguishes existing IS artifacts and IoT objects based on the primary purpose for which their designers designed them and/or their components. For example, traditional IS infrastructure components, such as a computer, a router, and a printer, all have computing capabilities as their underlying purpose. These items serve primarily as computing artifacts. In contrast, IoT objects refer to objects that integrate non-computing design purposes with computing or digital properties or that enable non-computing design purposes. To distinguish whether or not an object forms part of a system with IoT properties, one may find it useful to first separate the object's original (design) purpose from the digital properties that it possesses or vice versa. With this distinction, one can more clearly position components in theorizing about traditional IS artifacts versus IoT objects.

The design purpose's relevance as a distinguishing IoT characteristic rests on the fact that it compels scholars to take a step back in evaluating an IoT system's components before viewing them based on prior assumptions with which they have traditionally considered IT artifacts. For example, one could arguably dismiss a spoon that acts as a thermometer that interfaces with a health kit that then communicates with a fridge to decide a person's grocery list as an IS setup of devices with embedded software and communication protocols. Although such a view is somewhat accurate, it does not clearly distinguish the "things" in the scenario (Barnaghi, Wang, Henson, & Taylor, 2012) and imposes a familiar IS conception on them. Such conceptions logically come along with preconceived notions and assumptions that limit one from exploring the interplay between the physical and the digital. We contend that the IoT requires the IS discipline to shift from a dominant focus on the digital to a view that considers and embraces the interaction between both the physical and the digital. With such a shift in perspective, we can open up new theoretical frontiers as opposed to forcing the IoT into prior models.

3.1.2 Everyware

Everyware reflects an expansion in what qualifies as hardware in the computing sense from physical computing technologies to regular objects. It stems from the fact that the IoT enlarges the scope of hardware in IS to "everyware" (Greenfield, 2006). The everyware notion (a term that Greenfield (2006) coined) captures the propensity for literally any object to become a component in an IoT system (Wiberg, 2018). In IS research, we generally consider IT systems as having at least three key components: hardware, software, and data (Patterson & Hennessy, 2013; Pitt, Watson, & Kavan, 1995). In an IoT system, however, the view of what embodies an IT system expands. This change requires that scholars move from the hardware perspective to the "everyware" perspective. Hence, although we have typically considered IT systems to include hardware, software, and data, IoT comprises everyware, software, and data. Software and data remain largely with similar identity and composition in the IoT as in IT. However, the hardware concept expands in the IoT context to include not only IT hardware but also any and every object that one can make to possess a digital identity. We can consider the "things" concept in the IoT to capture this expansion (see our definition of the IoT). In essence, one can effectively convert prior mundane objects that do not qualify as hardware in a traditional IT sense into everyware in the IoT context with appropriate IoT technologies. This characteristic's distinctiveness comes into force when evaluating if a system constitutes an IoT system or a traditional IT system.

This characteristic may play an important role in future theorizing about IoT systems as it calls attention to objects' physical nature and properties beyond their IoT functionality. As a result, we may need to expand our lexicon to account for the change in what hardware means in an IoT context. Without such a distinction, researchers may have a tendency to consider all IoT objects and sundry hardware, which we argue would hinder them from uncovering the theoretical potential of engaging with the physical affordance that the everyware concept offers beyond prior perceptions of hardware. In summary, this distinction enables researchers to embrace IoT objects' "thingness" rather than bracketing them in our prior logic and assumptions about hardware in IS systems. The characteristic also highlights how viewing software and data as intrinsic IoT system components parallels how researchers have formerly conceived of systems in the IS discipline.

3.2 The "Internetness" Delineation

3.2.1 Data Lifeline

Data lifeline represents data's necessary presence as a fundamental requirement for any object to qualify for consideration as an IoT object. Whereas the first two characteristics emphasize the distinction between objects/artifacts in the IoT versus IT, data lifeline focuses on differentiating between IoT objects and regular objects. Considering the IoT's physico-digital nature, researchers can find value in going beyond the distinction between IT and the IoT to identify how IoT objects uniquely differ from other regular objects. The everyware characteristic creates an open question: when is a specific object a part of the IoT rather than just another regular object? Essentially, where is the boundary or point at which a regular object becomes potentially recognizable as an IoT object? The data lifeline characteristic provides one step in answering these questions. Data lifeline indicates that an object needs to have data capability (e.g., collection or creation) in some form or another to qualify as a potential IoT artifact. This characteristic proposes that the IoT construct ceases to exist without data. If an object loses its data lifeline— its digital quotient—it may still have its physical properties to fulfill its primary design purpose but no longer holds claim to being an IoT object. However, data lifeline represents a necessary but not sufficient characteristic to determine an object's classification as a component in an IoT system versus one that is not (which justifies the connectivity characteristic's value, which we discuss in the next section).

The data lifeline characteristic finds relevance in its capacity to delineate between whether an object potentially qualifies as an IoT object or a regular object. Data lifeline provides a simple metric for eliminating many regular objects from consideration as IoT objects, which provides practical utility in empirical considerations about the IoT. This delineation can also help one when considering instances where a sensor in an isolated object leads to one to consider such an object as an IoT object. For example, a revolving/sliding door or automatic light switch that automatically swings into action on detecting movement constitutes a regular object. One could potentially capture such an isolated interaction as data points or combine it with other data functionalities to make it an IoT object. However, the hardwired sensor logic in itself does not capture the notion of a data lifeline that an IoT object requires. Although the data lifeline represents an important precursor for an object to become an IoT object, it leaves open the possibility that an object that fulfills this characteristic may rather constitute an IS artifact. Hence, one needs to consider this characteristic in conjunction with another characteristic, connectivity, rather than in isolation.

3.2.2 Connectivity

Connectivity captures the need for objects to exist in connection to other objects in order to form part of an IoT system. Connectivity implies that an object is not a standalone object (Mitchell, 2004) but one that has the capacity to convey its data to other objects. Furthermore, this characteristic resembles data lifeline in that it alone represents a necessary but not sufficient precursor for an object to become an IoT object; we separate them because data and the mechanism to transfer it clearly constitute independent dimensions. Neither is sufficient alone as data and the mechanism to transfer data are clearly independent dimensions. One can use connectivity to differentiate the IoT from smart objects. By definition, the IoT implies interconnected objects and does not refer to objects that function in isolation. This differentiation resonates with Mitchell's (2004) rephrasing of Descartes' famous quote "I think, therefore I am" to "I link, therefore I am*"*. An object may function alone and have intelligent properties, but one would still better classify it as a smart object (say, a standalone robotic vacuum cleaner) than a part of the IoT if it does not connect to other objects. We also highlight that an artifact does not represent an IoT object on its own but only a component of an overarching IoT system and IoT as a whole. Hence, an object becomes part of an IoT system only when it has some form of data connection to the system and can communicate data either synchronously or asynchronously between different objects in it.

The connectivity characteristic helps researchers avoid automatically considering every object that has a sensor or handles data in some way as an IoT object. Further, the characteristic moves the system notion into the IoT domain. This characteristic suggests a relational and network perspective for considering the IoT. Such a perspective further brings the IoT concept to a granular level in which researchers can study the IoT as a collection of IoT objects. In addition, this characteristic helps researchers avoid mixing apples and oranges in theorizing about smart objects and the IoT and provides a lens for conceptually unpacking both concepts as distinct yet related theoretical and empirical domains.

4 Foundational Implications for Research on Information Systems

In this section, building on Section 3, we outline four areas in which the IoT leads to essential foundational implications for IS research: 1) the physico-digital continuum, 2) multilevel exploration of IS, 3) composite affordance, and 4) heterogeneity. These implications not only pertain to scholarship on the IoT but also encourage researchers to reconsider several broadly held assumptions that underlie information systems a whole. We believe that the IS research community needs to specifically consider the impact that changes in these four areas will have on systems that include IoT capabilities.

4.1 Physico-digital Continuum

The IS discipline has typically focused on different aspects of the digital, digitization, and digitalization (Fürstenau, Baiyere, & Kliewer, 2019; Tilson et al., 2010; Wessel, Baiyere, Ologeanu-Taddei, Cha, & Jensen, forthcoming; Yoo et al., 2010). However, IoT research has the potential to shift that focus to the digital, the physical, and particularly the interaction between the two. The IoT, by definition, requires the physical and digital domains to amalgamate. With the IoT, one can no longer view these two domains as disparate entities (Wiberg, 2018); rather, one must view them as an intertwined ensemble (based on the everyware delineating characteristic)—perhaps an anomaly to the call for an ontological reversal with the notion of “digital first” that Baskerville, Meyers, & Yoo (forthcoming) have advanced. In the IoT context, we may be witnessing an “ontological integration” rather than a reversal and the notion “digital too” rather than “digital first”. Given that researchers develop many IS theories to cater solely to the digital domain, the IoT opens up possibilities to a new frontier for re-evaluating IS assumptions and advancing novel IS theories that consider the interplay between the digital and the physical rather than simply ordering one before the other.

These possibilities raise questions about how we conceptualize IT artifacts when theorizing in the IoT context where the digital and physical elements naturally intertwine. The IoT’s physico-digital nature implies that IS scholars need to reflect on both the scope and definition of the central IT artifact that our studies revolve around. The change that the IoT heralds in this regard does not simply represent a change in technology but a fundamental expansion of our scholarly domain from the purely digital to areas where digital and physical act together. Although researchers could possibly disentangle the digital as a phenomenon from the physical in IoT studies, we argue that such an approach would deny the rich insights they could obtain by considering the physical and the digital as intertwined (Wiberg, 2018). The projections around the IoT’s growth suggest that what we consider IT today may be experiencing a shift where IT gradually becomes synonymous with the IoT in the future: it will be so commonplace for the digital and the physical to be intertwined that we will no longer need to label them separately. Thus, as a community, we would benefit from engaging in scholarship that expands our domain from the digital to the physico-digital. We perceive that such a transition will likely bring to fore a need to rethink what an artifact means in an IS study before we set out to desperately seek out the IT artifact as prior research has recommended (Orlikowski & Iacono, 2001).

This composite affordance further has implications for the IS discipline because it blurs how we conceptualize the boundaries of the core phenomena that we focus on. Prior to the IoT, we could straightforwardly outline a system’s boundaries and clearly delimit the IS artifact in focus based on the three components hardware, software, and data. With such a conception, one could regard other items in IS research as contexts, actors or non-IS artifacts. With the IoT, we need to rethink this conception to understand how to accommodate the shift in what we focus on studying in an IoT context. Such rethinking is particularly pertinent as it may reveal limitations in prior theories or sharpen their applicability in illuminating different conceptualizations of the boundary of our focus object in IS studies. As a result, we may redefine the discipline’s scope as we seek to further legitimize and strengthen our position and identity as an academic discipline (Benbasat & Zmud, 2003; King & Lyytinen, 2006).

Given that IS research has historically focused on digital elements, we have barely considered the materiality of the artifacts in our earlier core research streams. The design science paradigm and the Workshop on Information Technologies and Systems (WITS) community constitute perhaps the closest IS research genres that place some emphasis on the artifact’s materiality. This digital inclination over materiality has historically made sense as the discipline focused more on the artifact’s software and data applications and possibilities in social and managerial contexts. Along this reasoning, we considered the artifact’s technical or hardware aspects to relate more to the engineering and hard sciences. However, with the IoT, the materiality, which draws on artifacts’ physical properties, becomes an important component in understanding the IoT. We can no longer downplay the importance and relevance of the constituent materiality of the systems we study as the physico-digital combination provides a new perspective to examine them.

4.2 Multilevel IS Exploration

The IoT provides an avenue to conduct IS research that cuts across multiple levels of enquiry. Researchers have traditionally defined research in the IS discipline in terms of social, organizational, and managerial relations and placed less emphasis until recently on the individual outside the organizational context, such as personal use (Baskerville, 2011). With the notion of things in the IoT and its extension to everyday objects that individuals interact with regularly either in work or life contexts, the IoT provides unprecedented opportunities to study IS phenomena at finer levels of detail from the individual level to higher levels of analysis and abstraction. Because connectivity as a delineating characteristic leads to potentially highly intensive communication between IoT objects, we need to pay attention to both individual components' behavior and the outcomes that result from communication between system elements. Even in an organizational research setting, one can zoom in the level of granularity to pick minute details of individual-level phenomena in an IoT context. As an example, in an industrial Internet of things (IIoT) context, IIoT systems could holistically overview a manufacturing workshop while also providing deeper insights into individuals' practices and their interaction approach with the machines on the workshop floor. Similarly, studies around smart cities could provide a nexus for combining individual-level data and city data as an empirical basis for exploring the relationship between macro and micro events in a societal context (Bassoli, Brewer, Dourish, Martin, & Mainwaring, 2007; McCullough, 2004; Mitchell, 1996).

Although traditional IS theories address many different phenomena in organizational contexts quite well, one might wonder about their applicability to non-organizational settings. The IoT penetrates every aspect of life, which includes work and personal spaces (McCullough, 2004; Mitchell, 1996), and, thus, opens up new implications for how we think about IS across different levels and the extent to which prior theories apply in such multilevel contexts, particularly the undertheorized individual level (Vodanovich, Sundaram, & Myers, 2010). As Baskerville (2011, p. 251) notes, the emergence of individual-level issues in studying IoT devices as these devices become everyday objects is happening "just beneath the noses of information systems (IS) researchers". With an increased focus on the IoT, we may broaden our perspective and move beyond the organization as the dominant research context, which we can trace back to the days when individuals used trivial and simple (especially by today's standards) information systems.

4.3 Composite Affordance

Because IoT objects essentially bridge two disparate domains (i.e., the physical and the digital) (Stankovic, 2014), an IoT artifact's emergent affordance is the two domains plus the many other opportunities that emerge due to the artifact's interconnection with other objects. With composite affordance, the IoT's affordance emerges from the two constituent domains (physical and digital) with significantly different capabilities that, when combined, produce affordances different from the individual components. Everyware have many more capabilities than either software or hardware components alone. One cannot consider an IoT system with a singular focus on the digital or physical alone: one needs to consider the affordances that both offer both along with the affordance that their interaction enables (Leonardi, 2011) based on the design purpose and connectivity delineating characteristics that we discuss in Section 3. In essence, the point where the IoT departs from what prior IS research has focused on lies in the affordances that the IoT brings from the physical domain. Thus, these additional affordances expand what we can possibly study from examining the affordance that the digital domain alone offers.

Therefore, in our theorizing, we need to consider IS artifacts' possibilities and limitations. For example, it would be atypical for a traditional IS study to consider an IS artifact's affordance to include "sitting". However, in the IoT context in which one examines a chair as the IoT object or artifact, the "sitting" affordance becomes a logical capability that the IoT artifact affords in conjunction with other digital affordances that it inherits from the interaction between its physical and digital properties as an IoT object (e.g., a change of color if the chair's weight or temperature exceeds its specified limit). These composite affordances that the IoT raise have the potential to influence our theorizing to hold relevance for not only the digital domain but also the physical domain (Leonardi, Nardi & Kallinikos, 2012; Norman, 1999, 2008).

At the same time, by infusing composite affordances into our theorizing, we could reveal areas where we may need to refine and recalibrate our generalized assumptions.

Composite affordances also have the potential to highlight the IS discipline's role at the intersection of social, business, and technical scholarship (Baiyere, Hevner, Gregor, Rossi, & Baskerville, 2015; Baskerville et al., 2018; Benbasat & Zmud, 2003; King & Lyytinen, 2006), which we discuss in Section 5, because unwrapping an IoT's composite affordance would require studies that leap beyond the silo approach that characterizes most IS research to an approach in which studies draw on multiple perspectives. In the IoT era, IS scholarship has a unique capacity to leverage its peculiar intersectional nature to understand and build bridges between the different worlds that the IoT brings together: the technical world and social world, the Internet age and industrial age, and the digital world and physical world (Goles, Hawk, & Kaiser, 2008). In this sense, research studies on IoT could benefit from leveraging the IoT's technical characteristics and more deeply probing the underlying mechanisms through which IoT innovations enact themselves in our socio-technical structures. These studies also have the potential to reveal theoretical insights relevant to IS research on the behavioral, managerial, and design implications of their application.

4.4 Heterogeneity

Given its broad reach and complexity based on intensive connectivity, the presence of the IoT in a system context naturally introduces heterogeneity into the system (Barnaghi et al., 2012). For example, consider an IoT system that uses data from various traffic sensors and integrates the data with mapping capabilities to provide traffic guidance. This example highlights the way in which IoT capabilities introduce heterogeneous goals into a system. The goals an individual has for such a system will likely differ from the goals a community (city or town) or society has for it: when an individual might want to minimize travel time, the community might want to minimize traffic congestion and the society reduce the level of carbon dioxide emissions. Thus, these goals can not only differ but also conflict and, thus, require multilevel conversations among stakeholders to determine what goals to prioritize. Da Xu et al. (2014) have identified the same need to achieve a balance between competing goals in the IIoT context.

From another perspective, many IoT systems bring together various devices that differ except for the data they collect and the protocols at various levels that they use for communication (Barnaghi et al., 2012) and that make it possible for these heterogeneous components to interact. The disparate devices create a wide range of interactions that contribute toward the overall system experience. For example, a smart home may have a smart thermostat with manual controls, various sensors that provide data points for continuous security analysis (such as protection against potential break-ins, extreme temperatures, and flooding), voice-activated personal assistants, and digital control through a mobile app. To accomplish their goals, users may have to interact with the system via voice commands, gestures, screen interfaces, and physical controls in combination. Although researchers have made significant strides to understand the impact of consumer IoT-solution adoption through an integrated approach to the technology acceptance model (TAM) (See Gao & Bai, 2014), we need additional research to better understand IoT-system adoption among users and the implications that may emerge from a broad collection of heterogeneous interactions. In addition, from the design perspective, the heterogeneity of communicating objects in a typical IoT context raises important and non-trivial questions about how to necessarily standardize communication while maintaining the component heterogeneity that contributes to the richness of the system capabilities as a whole.

5 Thematic Research Opportunities

In Section 4, we discuss the IS characteristics that change based on IoT elements to highlight areas where the IoT leads to essential foundational implications for IS research and the implications for systems that include IoT elements. In this section, our perspective changes: we explore the ways in which IoT opens up research opportunities based on its impact on four major thematic domains: 1) organizations, 2) technology, 3) individuals, and 4) society. For each domain, we highlight possible topics, discuss the IoT's issues and potential significance in that domain, and comment on the theoretical implications. We do not focus on comprehensively covering all possible avenues of IS inquiry; instead, we focus on highlighting some key potential topics and providing an illustrative agenda for addressing the impact that the emerging IoT phenomena may have on major domains by drawing on the core characteristics and foundational implications that we outline in Sections 3 and 4, respectively.

5.1 Impact on Organizations

A lingering question in the conversation around the IoT in organizations (aligning with the IT and organizations theme in Sidorova et al. (2008)) today concerns how we can strategically position an organization to leverage the IoT while minimizing the impact of the challenges associated with it. The gains comprise the accruable benefits, value, and competitive advantage, whereas the pains include the disruption and challenges that may be associated with IoT, such as difficulties in getting access to qualified personnel (Shim et al., 2019). The IoT has potential for different types of organizations, but, depending on the type of outputs (products, services or technology), its utility and value appear to unfold differently. As prior research has demonstrated (Kleis, Chwelos, Ramirez, & Cockburn, 2012; Kohli & Grover, 2008; Nambisan, 2013), emerging IT innovations such as the IoT can create value for organizations by, among other things, 1) enabling them to improve their processes and organizational efficiency, 2) enabling them to digitize and enhance their products or service offerings, and 3) helping them increase their brand value and customer engagement (Baiyere, Salmela & Tapanainen, 2020; Endres, Indulska, Ghosh, Baiyere, & Broser, 2020). Therefore, IS research needs to examine how organizations can systematically build effective strategies to gain value from the IoT.

Additionally, as one can see the IoT as both a digital innovation opportunity and a digital-transformation opportunity, many organizations have yet to determine each dimension's implications and how to juggle them along with their many other priorities (Baiyere et al., 2020; Weill & Woerner, 2018). In an era in which new digital innovations continually emerge, organizations see the IoT as a channel with which to further infuse digitalization into their offerings. Similarly, the IoT represents an important asset in the digital-transformation process. Although some organizations see the IoT as an opportunity to incorporate digitalization into their products, others see it as a means to make gains through improved operational efficiency (Baiyere et al., 2020; Endres et al., 2020). Some organizations realize that the IoT's emergence could significantly disrupt their ability to achieve their goals and have begun exploring how to transform to address such disruption. In essence, many organizations are grappling with understanding how to leverage the IoT's opportunities while ensuring that its disruptive tendencies (Baiyere & Hukal, 2020) do not catch them by surprise. Organizations are trying to understand what it means for their business models, their product portfolio, and their operational processes (Endres et al., 2020). To address these issues, IS research can draw from the IoT's heterogeneity and composite affordance.

Specifically, in an industrial business context, researchers could conduct a multilevel exploration because the industrial IoT (IIoT) raises the possibility for a pan-organization business setup (Daugherty, Banerjee, Negm, & Alter, 2014). This pan-organizational possibility unfolds as both an obstacle and opportunity as organizations need to assess their capabilities and engage in atypical partnerships to leverage the IIoT's opportunities. It becomes imperative that organizations in such contexts think unconventionally about their customers, business models, trends, technologies, and capabilities to ensure they can compete in such an ecosystem. Leveraging the IIoT implies a transformation where traditional manufacturing organizations begin to assume some attributes that one would find in an IT company. Hence, such organizations will likely face more organizational rather than technical challenges, which raises research avenues across different levels, stakeholders, and industries. Researchers can find research opportunities in examining the interface between the distinct worlds and levels that the IoT interconnects. Such work would also afford an opportunity for multidisciplinary studies as IS researchers would need to work with scholars from many other disciplines to provide input or theoretical foundations. In general, IS research needs to examine the requirements, models, and implications of these new interconnected worlds and the skills required to thrive in an emerging IoT era.

From a business and management perspective, crafting a profitable and sustainable business model around IoT also constitutes a practical challenge that researchers should investigate (Endres et al., 2020). IoT innovations require business models that leverage both their physical and digital nature. However, few enterprises can proficiently create and capture value across the physical and digital domains. Typically, organizations can derive value from their investments in new innovations based on how successfully they deploy those innovations win a business model. Hence, the IoT's emergence as an important organizational initiative would drive an organization's search for business models that bring forth the IoT's potential value and leverage its dual digital and physical attributes. Studying ways to leverage the IoT to survive, compete, and thrive in the emerging IoT-driven business environments would constitute a valid approach under this theme. The emerging body of knowledge about the IoT implies that businesses are still trying to identify and implement unique and inimitable value propositions from it (Bilgeri & Wortmann, 2017; Dijkman, Sprenkels, Peeters, & Janssen, 2015; Leminen, Westerlund, Rajahonka, & Siuruainen, 2012). Managers who contemplate adopting the IoT face a dilemma in realizing its potential benefits while minimizing the burden from its uncertainties.

IS research has many opportunities to demonstrate relevance and contribute meaningfully to IoT research from a business and management perspective. An essential research agenda for IS in this regard involves bringing clarity to the IoT's complexity and the misconceptions about it that proliferate in both the practitioner and academic domains. Clear constructs, concepts, and limitations would provide value to theory building in this research endeavor. At the same time, conceptual clarity would help practitioners understand actual possibilities versus the hyped possibilities, understand different application areas and their limitations, and provide guidance in engaging in IoT initiatives. Further, based on the issues that we highlight above and the potential inherent in IoT from this perspective, IS researchers have an opportunity to generate theoretical insights from examining the extent to which our prior assumptions hold when following an IoT logic to create and capture value. Such theoretical expositions can help explain how organizations can create, capture, and distribute value internally and across business ecosystems. Existing research streams that researchers may potentially draw from and make theoretical contributions to include IT strategy, IT governance, IT security, digital innovations, digital transformation, economics of IT, business processes, digital workforce, and digital business models.

Illustrative (though certainly not exhaustive) questions under the organizational perspective, which we provide to provoke and stimulate ideas around the IoT, include:

- How well do IS theories account for how organizations derive business value in the IoT era?
- Do we need new theories to capture the IoT's business value?
- How can we adapt IS theories to capture the IoT's multilevel, composite-affordance, and heterogeneous nature?
- What organizing logics can organizations use to leverage the IoT in a business context? What roles and responsibilities do IT organizations have in the IoT era?
- What relevant theoretical underpinnings can one use to unpack the complex stakeholder ecosystems that characterize the IoT business landscape?
- How can businesses deal with the system integration challenge given the IoT's physico-digital nature?
- What forms of collaboration, open innovation, and co-creation have begun to emerge in the IoT era?
- How should one coceptualize IoT business models to address the challenges and economic opportunities that the IoT affords?
- What opportunities do IoT-based systems create in governmental and not-for-profit contexts?

5.2 Impact on Technology Applications

Given that increasingly more devices have the capacity to sense, communicate, and actuate in a dynamic setting, we face significant design and technical complexities. For instance, the growth in these devices has implications for the quality and reliability of the services that depend on them. Failures and security breaches pose a real and imminent concern. As such, we need to pay attention to how designers design these systems. This domain aligns closely with the IS development research area that Sidorova et al. (2008) discussed. With its high level of uncertainty, the IoT provides ample opportunity for research that looks into the fundamental principles of design, development, and functional capabilities, particularly from the perspective of the design principles and practices that IoT capabilities require. Researchers also need to examine how we can standardize IoT devices and the mechanisms by which they communicate with one another. Due to the IoT's interwoven sociotechnical nature, researchers could conduct studies on standardization in not only technology contexts but also application and practical contexts. A need for a shared understanding and lexicon for interoperability across different channels and different application scenarios also represents a potential opportunity for further IS inquiry. We also believe that researchers will add value to the literature via conducting studies that also consider the heterogeneity, composite affordances, and behavioral semantics that play an equally important role in designing and standardizing IoT applications.

Concern around IoT data poses another issue that we should consider as a possible agenda item for IS research as it drives to the heart of the IoT's physic-digital implications. One faces challenges in managing and consuming data from an IoT deployment because one needs to normalize the data from diverse sources and devices. An IoT instance needs to congruently handle both historic and real-time data that involves multiple deployment methods. These complexities create key data challenges that impact an organization's ability consume and fully use the data it collects. Typically, IoT-application deployments comprise massive numbers of devices and endpoints including cameras, microphones, smoke alarms, and sensors that use various communication standards. These devices transmit vast amounts of heterogeneous data, which creates a significant challenge in managing the data as each device may have a different protocol, transport requirements, and structure. Further, the data may come from disparate sources that have specific restrictions and needs. For example, a smart city deployment may collect video streams and traffic information from government sources that require strict security compliance (Bassoli et al., 2007). Data then may enter the stream from private data sources that handle user profile information from IoT applications that run on mobile devices. As the city directs users to open parking spaces from its applications, it could notify local restaurants and shops so that they can push promotions, such as sales and lunch specials, to interested potential customers.

From a multilevel perspective, this data comes together to help the city intelligently manage its infrastructure and bring in more visitors. It helps local businesses increase their foot traffic and conversion rates and improves both citizens and tourists' lives by saving time and creating a stronger sense of security. However, we still have much ground to cover in understanding how to derive value from the vast amount of heterogeneous data that comes from devices with varying protocols and technical and physical specifications. In this challenge lies an opportunity for IS research from a technical and design perspective. In addition, the IS discipline has a unique capacity to address questions related to data's role in the IoT context. For instance, researchers could explorethe perspective of the required high-level analytics infrastructure, the integration of data from IoT-focused systems with other organizational systems, and the management of data at the system level. The IS discipline has the potential to contribute in a significant way to the discussion on big data's implications and potential consequences (Markus & Topi, 2015).

Additionally, IoT deployments continue to attract concern about the exponential increase in security risks associated with the rapid increase of connected devices. The International Data Corporation (IDC) has indicated the potential for about 90 percent of IT networks to have an IoT-based security breach (Turner, MacGillivray, Gaw, Clarke, & Morales, 2014). Due to the vast variety in devices, protocols, applications, and other elements in an IoT environment, a natural barrier that prevents IoT exploits and attacks may exist. Paradoxically, this variety can also open up various entry points for attack as it equally implies more vulnerability outlets for malicious infiltrations. The increasing number of IoT deployments and the potential value of the data in these environments may entice attacks across industry, government, and consumer IoT systems. Therefore, policy regulations and security protocols need to address vulnerabilities from the physical IoT device end points through the digital data pipeline to both public and private cloud infrastructure and to protect data as it moves to end devices that consumes the insights from analytics, which further illustrates the need to take a multilevel perspective in investigating the IoT.

In terms of application design and user experience, IoT devices are highly specialized and, therefore, vary drastically. IoT applications' ability to deliver value to users depends on highly complex architectures that span across a vast array of various device types, platforms, and network/infrastructure paths. Due to these architectures' nature, many points may cause friction between a user's experience and the IoT deployment. Additionally, users may interact with various devices across the stack through gestures, voice commands, eye tracking, bio-informatics, and traditional graphical user interfaces (GUIs) (Rowland & Charlier, 2015). The spectrum of research opportunities continues to broaden. For example, considering IoT application design and user experience in the health domain, wearables' role will continue to grow, and the process of optimizing patients' experience will continue. Although researchers have conducted some research in this area, we require additional models, design practices, and user experience (UX) measures to evaluate various device types that may have different functions across the entire stack of physical and digital domains, which open up gaps that future research needs to understand and address.

5.3 Impact on Individuals

IoT capabilities have a potential major impact on individuals both in and outside organizational contexts, which leads to significant new research opportunities in the IT and individuals research theme that Sidorova et al. (2008) present. For example, adoption, use, and benefits realization constitute key focal points in the technology-adoption domain (see also Venkatesh, Morris, Davis, & Davis, 2003; Venkatesh, Thong, & Xu, 2016b). Recent work has suggested that, in various consumer contexts, users adopt and use technology voluntarily (see Venkatesh, Rai, Sykes, & Aljafari, 2016a; Venkatesh et al., 2016b). The social changes that result from IoT devices may have fear-reaching consequences and result in various lifestyle changes (Mitchell, 2004). We can already see that smart watches can affect work-life balance and intrude on individuals' personal time even more than occurred with mobile phones. We also note a need for more and continuing research on such non-work individual IoT adoption and use, especially because much IS research on adoption has focused on technologies that target employees. However, with the IoT, personal non-work technology use may become more salient as a component to consider in future theorizing. We suggest that such a focus has the potential to be a fertile arena for IoT research and to reorient many assumptions (see Schuetz & Venkatesh, 2020).

Related but distinct from the IoT's impact on individual behavior concerns its large-scale impact on healthcare. The IoT has perhaps greatest (positive) social transformation potential in healthcare in both developed and developing countries. In a developing country context, even traditional technologies may contribute to large-scale societal transformations such that the IoT may engender even greater change, such as empowering women (Venkatesh, Shaw, Sykes, Wamba, & Macharia, 2017). Although users may continue to largely adopt IoT technologies voluntarily, they may not be able to avoid them in some cases (e.g., some IoT devices may automatically transmit data). Questions regarding adoption become particularly complex in the healthcare context since healthcare providers require patients to provide data to improve healthcare delivery and prevent problems (Chatterjee et al., 2018). For example, even though a healthcare professional might set up a wearable IoT device correctly, a patient could subsequently intentionally or unintentionally modify the settings that compromise the healthcare provider's goals and, in turn, compromise care quality. All these factors point to the need for researchers to examine IoT-adoption and -use contexts in a more sophisticated and nuanced manner. Specifically, IoT-adoption and -use studies should help advance scientific knowledge tied to this key new technological development. A study that examines specific IoT technologies' design features and how they may, in turn, influence key predictors (e.g., performance expectancy) in technology adoption models would represent a useful direction that tackled this problem from not only a social/behavioral perspective but also a design science perspective (Baskerville et al., 2018; Venkatesh et al., 2016a; for an example, see Zhang, Venkatesh, & Brown, 2011). Prior research on mobile technology adoption and use could provide potential input in this area (see Thong, Venkatesh, Xu, Hong, & Tam, 2011).

Other research opportunities build on the context notion above and include additional opportunities in the healthcare context. Above, we discuss practical issues related to IoT in healthcare. IoT devices go a step further in being far more intrusive and intimate in terms of how they relate to a patient's life and activities. We can reasonably expect that the theoretical approaches that researchers will use will have to be far more inclusive in terms of individual reactions to technologies that will actively record, monitor, and share private information. Going a step further, the fact that patients who have various (potentially life-threatening) ailments will potentially use IoT technologies in healthcare settings (Chatterjee et al., 2018) will necesstitate a paradigm shift in terms of what theories and constructs drive adoption and use.

Finally, security and privacy issues constitute another specific area that emerges from the general notion of the individual-use context and has a major impact on use. Oriwoh, Sant, and Epiphaniou (2013) draw attention to the fact that new cybercrimes typically emerge when actors develop and deploy new technologies. They claim that a wave of privacy and security breaches will likely accompany the IoT. Given the rate at which technology (and the IoT in particular, which includes its anticipated diffusion and adoption) continues to change, legislation will inevitably lag behind the IoT. Indeed, the IoT requires government and legal oversight over how it operates even now in its formative stages. The IoT will profoundly influence our domestic, work, and social environments; therefore, we should see legal and policy discussions around it as critical for its development. Researchers could provide answers to associated issues, such as not processing, tracing, and profiling people in an unlawful manner. In this way, they could help design data protection-friendly technologies. In terms of security in the IoT, security researchers in the IS community have the competencies to be able to provide an important new set of perspectives, particularly because they can seamlessly integrate policy and technical perspectives (Kayworth & Whitten, 2010). Although IS research has previously studied privacy and security (and the concomitant issues surrounding trust and risk), researchers still need to examine IoT technologies in various contexts such as healthcare. In doing so, they can better understand how existing knowledge related to these key concepts will generalize to the IoT and what new constructs/mechanisms/theories we may require. Here too we emphasize that various contexts may result in the need for various new constructs/mechanisms/theories.

5.4 Impact on Society

A societal perspective naturally amalgamates the organizational, technology, and individual perspectives that we discuss throughout the paper. A society-level research agenda deserves separate attention as many implications from the IoT's proliferation manifest at this level. We also call for IS researchers to strive for societal relevance beyond ivory tower theorizing with little consideration about how they can contribute to society at large. Recent calls have highlighted the need for IS research to engage with technology's societal impacts and consequences (Majchrzak, Markus, & Wareham, 2016). In this regard, we highlight three broad avenues for IoT research at this level: 1) societal benefits, 2) consequences, and 3) ethics.

In terms of research on the IoT's societal benefits, we have discussed much already in terms of the IoT's promise across all levels (e.g., the IoT's significant role in various initiatives such as smart cities, smart grids, and smart agriculture). However, we need to unpack the mechanisms and processes through which we can achieve these promises and intended consequences in practice. Key questions for IS research include:

- How can the IoT can serve as a catalyst for achieving national progress and social transformation?
- In particular, how can existing social and institutional frameworks accommodate the advances that the IoT promises?
- Or, conversely, how should we modify existing frameworks to enable society to harness the value inherent in IoT applications?

To answer these questions, researchers would need to push the envelope in multidisciplinary and multilevel research in various areas, such as legislation, policy making, climate change and disaster management. As Wirtz, Weyerer and Schichtel (2018) note, the IoT is emerging as a source of growth and innovation, but we still need to examine how we can tap its potential to realize societal benefits. Accordingly, future research should think about the value of context and question a "one-size-fits-all" paradigm, especially as we develop societal research around the IoT.

As Kling (2003) notes, not all technological advances are universally positive. Hence, researchers also need to explore the IoT's undesirable consequences at a societal level. For example, many have lauded the IoT for ushering in new approaches that may or may not require a human in the loop and eliminate human errors and related issues. Yet, beneath this glamorous outlook lies the uncomfortable reality that many jobs may become obsolete, which recalls the old argument about machines and automation replacing people and taking away their jobs (Brynjolfsson & McAfee, 2014). Such dilemmas mean that scholars need to examine how we can leverage the IoT's benefits while minimizing its negative implications on society. On a related note, an optimist would argue that technology creates as many jobs as it destroys. Yet, even this view exposes a different set of societal issues (e.g., education). If technology does not take away but reconfigures jobs, how should we educate the future workforce for them? Given that the IS discipline straddles technology, business, and society, it has a pivotal role in informing educational policy and championing research on how to answer questions about education in a world where the IoT is pervasive and the norm.

Lastly, from an ethical perspective, actors who plan, develop, and operate IoT systems have an obligation to assure information integrity and that the systems contribute overall to the public good (Fidler & Rogerson, 2001). Disclosive ethics (Brey, 2000) represents a particularly important concept in the context of new emerging technologies such as the IoT (Zuboff, 2019). Brey (2000) argues that complex technologies bring with them new moral problems precisely due to their complexity and opaqueness for non-experts. As such, technologies that appear morally neutral may, in fact, embody significant normative implications (Mitchell, 2004); hence, a need to reveal and disclose such characteristics emerges (Mingers & Walsham, 2006). Introna (2005) gives an example of disclosive ethics concerning facial-recognition systems. Social justice includes problems such as the digital divide that insufficient access to the technological infrastructure causes (European Comission, 2008). Thus, as the general research theme of IT ethics continues to grow in importance, we see particular challenges with respect to developing and deploying IoT devices. These challenges form part of the emerging research agenda in which the IS community can provide value, especially as we have long engaged with the digital realm and can benefit from collaborating with scholars from other disciplines such as sociology in attending to the IoT's multilevel, heterogeneous, and composite-affordance aspects. Lessons learned from IS research on the implications and potential consequences of big data and analytics (Markus & Topi, 2015) can provide guidance for similiar scholarly work in the IoT context. Another example concerns decentralization, particularly considering the practical, social, and ethical challenges that emerge when one or two global digital platforms centrally control most IoT data—what Zuboff (2019) calls surveillance capitalism.

6 Conclusion and Recommendations

In this paper, we highlight broad focal areas that indicate how the IS discipline can provide distinctive contributions to scholarly work on the IoT. These wide-ranging categorizations help researchers articulate the different areas of inquiry in the context of prior research classifications. However, this division into categories should not preclude researchers from examining each agenda item in other categories. To the contrary, we posit that the IoT's multidisciplinary nature will warrant studies that cross over multiple modes of enquiry and require researchers to blur the lines between these categories. The IoT's wide umbrella will likely provide a rich variety of research questions that IS researchers can uniquely address to provide significant value to many different stakeholders. In many cases, a synergy in the perspective of the design and behavioral paradigms may yield even more interesting insights. We suggest two separate perspectives on the research agenda: one that focuses on the IoT's conceptual implications for IS research as a whole and the one that focuses on three thematic domains (organizations, technology, and individuals in society). In doing so, we demonstrate that many IoT-related research topics cross the boundary between implications and domains—the issues span perspectives. We encourage the IS community to integrate research approaches and conduct cross-disciplinary research on the IoT.

We summarize some key research agenda items that cut across all the themes (particularly the call for future research and indicative research questions that we discuss in the paper) in Table 2 (next page). Note that we provide these items as illustrations only, and many may involve multiple levels or themes—we adopt the thematic representation that we use throughout the paper mainly for simplicity.

A natural point of opportunity for the IS discipline with regard to the IoT relates to contextualizing extant theory in the IoT context. In all likelihood, although existing theories provide a useful starting point, we will likely need to significantly contextualize and modify these theories to understand the IoT phenomenon in general and do so to an even more nuanced degree with particular technologies. Broadly, Johns (2006) notes that contextualized, rather than general, theories are particularly important. Alvesson and Karreman (2007) go a step further by suggesting that testing existing theories in a new context and the resulting breakdown creates opportunities for new knowledge creation. We organize the agenda for IoT research into four thematic domains as areas that information systems impact: organizations, technology, individuals, and society. Under each theme, we highlight the challenges and opportunities that open up research avenues for the IS discipline. Based on the outlined agenda, we present the overarching issues that will likely be particularly promising for IS research in the IoT context.

First, the IS discipline has a unique capacity address questions about how the IoT can transform organizations because our discipline integrates in-depth knowledge about IT with in-depth knowledge about domains of human activity, such as business, healthcare, and government. In particular, we have a particularly good capacity to analyze and propose various structural and process models to maximize the IoT's potential to generate value. More specifically, IS research on business process management, design, and transformation (Rosemann & Vom Brocke, 2015) should form a strong foundation for understanding the interdependencies in systems that depend on the IoT. Further, IS research can bring clarity to the conceptual complexity and ambiguity that makes it difficult to understand the true opportunities that IoT technologies create.

Second, the IS discipline has always managed technology development (IS development in Sidorova et al., 2008). Therefore, our discipline has a unique capacity to address questions related to issues in managing and organizing IoT development activities. Further, the IS discipline has particular strengths in addressing IoT strategy and governance issues. The discipline can also address the IoT's implications and potential consequences—its risks and potential pitfalls and its undeniable benefits for organizations and their implications for broader management research. Design science as a paradigm may contribute in significant ways to specifying and designing IoT platforms and systems and provide a significantly broader approach as compared to the narrow focus on technologies in many other disciplines (Baskerville et al., 2018; Chatterjee et al., 2018).

Table 2. Overview of Some IoT Research Opportunities

Theme	Sample research opportunity
Organization	• Build effective organizational strategies to create, capture, and deliver value across the physical and digital domains that characterize the IoT. • Explore how organizations should position themselves to accrue gains from and avoid disruptive associated with IoT innovations. • Understand the requirements, models, and implications of business in an interconnected world and the changing role of humans in the loop. • Develop and acquire the requisite skills and capabilities required to thrive and compete in an IoT era. • Clarify the complexity and misconceptions of IoT that proliferate—clarity of constructs, concepts, and frameworks to enable cumulative theory building. • Rethink and update prior assumptions with the IoT's emerging organizing logics and peculiarity. • Examine how one can adapt IS theories to capture the IoT's multilevel, composite affordance, and heterogeneous nature. • Examine IT departments' roles and responsibilities in the IoT era.
Technology	• Examine the fundamental design principles, development practices, and functional capabilities that IoT innovations require. • Standardize IoT devices and the mechanisms by which they communicate with one another. • Examine how we can deal with the system integration challenges given the IoT's physico-digital attribute that cuts across multiple discipline and expertise. • Consider the heterogeneity, composite affordances, and behavioral semantics that one needs in designing and standardizing IoT applications. • Address the complexities and challenges that impact the ability to collect, consume, and utilize data. • Explore how we can integrate data from IoT-focused systems with other organizational systems and manage such data. • Address concerns over IoT deployments and the exponential increase in security risks associated with the rapid increase of connected devices. • Research models, design practices, and user experience across various devices with different functions over the stack of the physico-digital continuum.
Individual	• Examine the implications and consequences that may arise from the various lifestyle changes that result from individuals using the IoT. • Examine the potential for non-work IoT to be a fertile arena for research that reorients assumptions from prior dominant organization perspectives. • Take a much more sophisticated and nuanced look at IoT-adoption and -use contexts. • Study individual-focused IoT devices' design features and how they may influence key predictors (e.g., performance expectancy) in technology adoption models. • Consider theoretical implications of individual's reactions to IoT technologies that can actively record, monitor, and share very private information. • Provide answers to issues such as actors who unlawfully process, trace, and profile people and design data protection-friendly IoT technologies. • Examine how existing IS knowledge/concepts generalize to the IoT and what new constructs/mechanisms/theories we may need. • Unpack the mechanisms and processes through which we can achieve the IoT's promises and intended consequences in practice.
Society	• Uncover the relevant theoretical underpinnings for unpacking the complex stakeholder ecosystems that characterize the IoT business landscape. • Uncover the opportunities that IoT-based systems create in governmental and not-for-profit contexts. • Assess policy regulations and security protocols to address vulnerabilities from the physical IoT device end points, data pipeline, and cloud infrastructures. • Strive for societal and practical relevance beyond ivory tower theorizing. • Engage with the IoT's societal impact and consequences such that we can leverage the benefits while minimizing its negative implications on society. • Examine how the IoT can serve as a catalyst for achieving national progress and social transformation. • Examine whether existing social and institutional frameworks accommodate the advances that the IoT promises or whether we need to alter them. • Examine how we could inform educational policies for a future workforce who live in a world with pervasive IoT and humans still have an ambiguous role. • Examine how we can leverage cross-disciplinary research to handle emerging ethical and moral dilemmas of incorporating the IoT into society.

Third, IS research paradigms such as design science and behavioral research have an opportunity to uncover interesting insights about the impact that the IoT has on individuals and societies. We believe that the IS discipline can better understand issues related to IoT adoption and use than any other discipline. Based on research on contextualization, we note that we particularly need to develop contextualized theories to understand specific aspects of IoT technologies and systems built on them in a deeper and more nuanced way.

In summary, the IS discipline's key strength in contributing to the IoT comes from our ability to examine a phenomenon from the social, technical, and business perspectives and to further leverage these distinct research perspectives to provide theoretical and practical insights. Further, our distinctive capabilities in understanding and modeling how the various layers of this complex and highly interactive system work together, how we can harness the system as a whole to advance human and organizational agents' goals, and what intended and potential unintended consequences that IoT-based systems may have make these areas potentially fruitful ones that we can contribute to.

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