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Blockchain Research in Information Systems: Current Trends and an Inclusive Future Research Agenda

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Abstract

The potential of blockchain has been extensively discussed in practitioner literature, yet rigorous empirical and theory-driven information systems (IS) research on blockchain remains scarce. This special issue addresses the need for innovative research that offers a fresh look at the opportunities and challenges of blockchain. This editorial integrates and goes beyond the papers included in this special issue by providing a framework for blockchain research in IS that emphasizes two important issues: First, we direct the attention of IS research toward the blockchain protocol level, which is characterized by recursive interactions between human agents and the blockchain protocol. Second, we highlight the need for IS research to consider how the protocol level constrains and affords blockchain applications, and how these constraints and other concerns at the application level lead to changes at the protocol level. Rooted in a socio-material view of IS, we offer a multiparadigmatic IS research agenda that underscores the need for behavioral (individual, group, and organizational), design science, and IS economics research on blockchain. Our research agenda emphasizes issues of blockchain governance, human and material agency, blockchain affordances and constraints, as well as the consequences of its use.

Keywords: Blockchain, Distributed Ledger Technology, Behavioral, Design Science, Economics of IS, Research Agenda.

1 Introduction

A blockchain is an append-only distributed database of transactions, characterized by high tamper-resistance, despite the lack of defined central operator. Blockchains are believed to fundamentally transform our economies and societies—in particular, by lowering transaction costs and reducing the need for trusted third parties (Catalini & Gans, 2016; Clemons, Dewan, Kauffman, & Weber, 2017; Iansiti & Lakhani, 2017).

Blockchain's potential to transform markets and societies has motivated public and private

organizations to make deep investments. Investors have backed blockchain-enabled cryptocurrencies such as Bitcoin, which have attracted substantial interest in financial markets (Mai, Shan, Bai, Wang, & Chiang, 2018) and mixed assessments from regulators (Guo & Liang, 2016). More ambitious applications have also been proposed, most of which rely on blockchain-based smart contracts—i.e., algorithms stored on the blockchain, meaning that their execution is de facto guaranteed (Buterin, 2014). Recently, a joint venture between Maersk and IBM was announced that aims to substantially increase the efficiency and security of moving products across the globe (Nærland, Müller-Bloch, Beck, & Palmund,

2017). Collectively, important actors agree that blockchain could impact many aspects of our societies from environmental sustainability (Chapron, 2017) to healthcare (Gammon, 2018) and social networks (Ciriello, Beck, & Thatcher, 2018).

While organizations have invested in exploring blockchain's potential, information systems (IS) research investigating blockchain remains scarce. Some early work has offered insight into how to design applications based on blockchain-based smart contracts (e.g., Egelund-Müller, Elsmann, Henglein, & Ross, 2017). Other work has examined the use of cryptocurrencies in practice. For example, Li and Wang (2017) conducted an empirical study on the determinants of cryptocurrency exchange rates in the case of Bitcoin.

Despite such exceptions, scant work in IS contributes to forming a theory-driven or rigorous empirically derived understanding of blockchain and its implications (Beck, Avital, Rossi, & Thatcher, 2017). This special issue jump-starts the scholarly conversation about blockchain in two important and meaningful ways: first, by presenting cutting-edge IS research addressing this gap and, second, by employing this editorial to set an agenda for future IS research studying the opportunities and challenges of blockchain. This special issue emphasizes inclusivity by considering three major paradigms in IS research (behavioral, design, and economics), both in terms of the three papers included in the special issue and with respect to the research directions provided in this editorial. We will now provide an overview of the three papers in the special issue and subsequently present our own thoughts and suggestions for blockchain research in the IS community.

To begin with, in "Self-Organising in Blockchain Infrastructures: Generativity Through Shifting Objectives and Forking," Andersen and Ingram Bogusz develop the idea of self-organizing infrastructures. This is achieved through a longitudinal case study of forking within the Bitcoin blockchain infrastructure. The case reveals how diverging objectives of different implementer groups lead to forks that can result in incompatible subversions of the infrastructure. These are interpreted as manifestations of self-organizing within the growing community. The main theoretical contribution here is the description of different patterns of self-organizing within the Bitcoin community and their connection to development events.

In the second paper, "Privacy-Preserving Data Certification in the Internet of Things: Leveraging Blockchain Technology to Protect Sensor Data," Chanson, Bogner, Bilgeri, Fleisch, and Wortmann follow a design science research methodology to

develop a blockchain solution for Internet-of-things (IoT) systems in the context of used cars. The paper deals with the problem of insecure communications and data storage in IoT devices by iteratively designing a blockchain-based system for protecting IoT sensor data. The design principles derived are evaluated with experts in an ex post evaluation step and then reported as an initial design theory for protecting IoT sensor data generation and processing. This paper combines a novel design, design theorizing, and practical implications, which is rare in one design science research paper.

Finally, in "Business on Chain: A Comparative Case Study of Five Blockchain-Inspired Business Models," Hua, Chong, Lim, Zheng, and Tan examine how firms leverage blockchain to create and capture value in novel ways. Through an exploratory comparative, multiple case-study approach, the authors analyzed the experience of five companies in mainland China that rolled out blockchain initiatives. From these case analyses, they derived a typology of five blockchain-inspired business models (platformer, disintermediator, mediator, transformer, and co-innovator), each of which embodies distinctive logics for market differentiation. In doing so, they offer insights into each model's value creation logic, its value capturing mechanism, and the challenges that could threaten its longer-term viability.

This editorial is structured as follows. In Section 2, we articulate our key concerns about blockchain research in the IS field and introduce a framework that directs the IS discipline's attention beyond blockchain's applications toward understanding the blockchain protocol level and its interactions with blockchain applications. In Section 3, we discuss critical issues at the blockchain protocol level and their interactions with blockchain applications, both of which we deem important for future IS research on blockchain. In Section 4, we use the framework to provide a forward-looking research agenda that connects blockchain to three major paradigms of IS research: behavioral (individual, group, and organizational), design, and economics. Section 5 concludes.

2 A Framework for Blockchain Research in Information Systems

Recent work in top IS journals has emphasized blockchain's potential to transform organizations and economies. Beck, Müller-Bloch, and King (2018) explore how blockchain may spark new forms of governance and organizations, while Clemons et al. (2017) articulate how blockchain may lead to broader economic changes. Others focus on blockchain's ramifications for specific firm competencies such as business process management (Mendling et al., 2018) or accounting (Dai & Vasarhelyi, 2017), or specific

industries such as Fintech (Gomber, Kauffman, Parker, & Weber, 2018) or e-government (Ølnes, Ubacht, & Janssen, 2017). All of these papers emphasize different facets of blockchain research in IS. Most of these articles direct attention to blockchain as a tool or application to solve business or societal problems.

While studying applications is consistent with the IS tradition, we believe our discipline needs to go beyond examining specific blockchain applications and toward understanding the broader implications of blockchain protocols. We do so, since not only extant work on blockchain in leading IS journals, but also the majority of the 37 special issue submissions focus on applications of blockchain to business problems. While such research is important, extending our field's focus to examining the blockchain protocol level as well as its interactions with the blockchain application level is critical for IS research to contribute to a more refined understanding of the socio-materiality of blockchain.

The key artifact of the blockchain protocol level is the *blockchain protocol*. It defines the technical rules under which the blockchain is produced. Table 1 shows that these rules, in particular, pertain to human agents' rights to validate transactions (as defined in the consensus protocol) and to read and submit transactions (Peters & Panayi, 2016). For instance, Bitcoin's blockchain protocol excludes human agents¹ neither from validating transactions nor from reading and submitting transactions. Therefore, it would be classified as permissionless and public, according to Table 1. The blockchain protocol also incorporates additional rules, such as the existence and extent of transaction fees and the maximum number of transactions the blockchain can handle within a given time. However, at the blockchain protocol level, we find more than just "mere" technology in the form of the actual blockchain protocol—indeed, it is characterized by recursive interactions between human agents and the blockchain protocol. Blockchain protocols not only result from extensive negotiations over design choices between human agents, they also require constant affirmation and

renegotiation of the agents over these rules, and changes to the protocol may follow. Moreover, human agents can undermine the blockchain protocol. At the same time, the blockchain protocol exerts material agency.² It directly governs the interactions of human agents by mediating their competition, cooperation, conflicts, and conflict resolution. Human agents govern the blockchain protocol, and the blockchain protocol governs their interactions. Therefore, blockchain directs attention not only to governance *of* information technology, but also to governance *through* information technology. The blockchain protocol is imbricated with the human agents' social world. This means that both are simultaneously interdependent, yet maintain their distinct irreducible character (Leonardi, 2011; Sassen, 2006). Over time, the interweaving of human agency and material agency (i.e., the blockchain protocol) may become taken for granted ("black-boxed") and, therefore, infrastructure, or more specifically, blockchain infrastructure may be taken for granted as well (Star & Ruhleder, 1996; see also Andersen and Ingram Bogusz in this special issue).

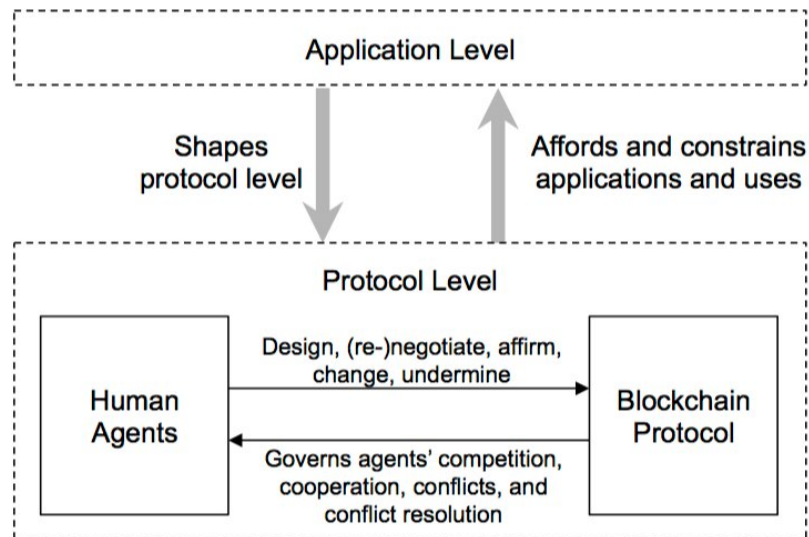
Besides the protocol level itself, there are critical interactions between the protocol level and the application level, given that the protocol level exerts affordances and constraints on applications and that actions at the protocol level are shaped by concerns about applicability and other developments at the application level. In this context, salient concerns include privacy, scalability, security, and environmental sustainability (we elaborate on these issues and their relevance for IS research in Section 3 of this editorial). Both the protocol level itself and its interactions with blockchain applications therefore merit special attention from an IS perspective. Our proposed framework for IS research on blockchain integrates the above thoughts and ideas and guides our directions for future research (see Figure 1). We elaborate in the next two subsections and then conclude in the third subsection by addressing the state of IS research on blockchain applications.

¹ In this paper, we use the terms "human agent" and "agent" interchangeably. Whenever we refer to material agents, we explicitly state it.

² Leonardi (2011) defines material agency as "the capacity for nonhuman entities to act on their own, apart from human intervention."

Table 1. Key Dimensions of the Blockchain Protocol

	Access to transaction validation	
Access to transactions	Permissioned	Permissionless
Public	All agents can read and submit transactions. Only authorized agents can validate transactions.	All agents can read, submit, and validate transactions.
Private	Only authorized agents can read, submit, and validate transactions.	Not applicable

**Figure 1. Framework for Blockchain Research in Information Systems**

2.1 The Blockchain Protocol Level

First, studying the protocol level represents fertile ground for important IS research since, at the protocol level, human agents interact within the rules set by the blockchain protocol, while at the same time negotiating these rules via the blockchain protocol. A discussion of *consensus protocols*, perhaps the most salient aspect of blockchain protocols, reveals how the protocol level is socio-material: Given that blockchains function without a defined central operator, there is a need to avoid disagreement about what information is stored on the blockchain. A lack of consensus would lead to the creation of alternative blockchains known as forks (Andersen & Ingram Bogusz, 2019; Decker & Wattenhofer, 2013). Consensus protocols address the issue by specifying how the right to validate new transactions (which are stored in batches called blocks—hence the name “blockchain”) is assigned. They do so by defining the basic rules that distribute decision-making power

among human agents. For instance, in the proof-of-work consensus protocol used by Bitcoin, decision-making power is distributed proportionally to the expenditure of computational power without external utility (i.e., mining). The agent with the most decision-making power is most likely to accrue the right to add a new block to the blockchain. Randomization in the consensus protocol ensures that the agent with the most decision-making power does not acquire the right to validate every block, which is crucial since a high degree of centralization of decision-making power threatens the blockchain’s integrity (Bano et al., 2017; Tschorsch & Scheuermann, 2017).

What is important for IS research is that in this context the actions of human agents exert a powerful influence on the blockchain.³ Mediated by the protocol, the agents most often achieve consensus, but their behavior can also induce forks—both incidentally and deliberately. These forks can have different

³ Beyond negotiations of agents directly mediated by the consensus protocol, agents also negotiate and constantly

renegotiate the blockchain protocol in other social spaces such as online forums or in physical meetings.

consequences, such as the creation of alternative histories of transactions (typically the case with incidental forks), changes to the blockchain protocol, or both (typically the case with deliberate forks) (Andersen & Ingram Bogusz, 2019). In addition to inducing forks, agent behavior can also actively undermine the blockchain's integrity—for instance, if one agent seeking to undermine the blockchain were to obtain the majority of decision-making power in the consensus protocol. In blockchains with proof-of-work as a consensus mechanism, for example, this would be possible if the agent possessed more than half of the computing power used to mine new blocks (Nakamoto, 2008). Another aspect is that the presence of agents is needed to run and secure the blockchain—if agents willing to participate in the consensus protocol are absent, transactions cannot be added to the blockchain and the blockchain's integrity is compromised. Clearly, issues of governance, as well as agents' motives and incentives, are critical for the blockchain protocol level. Given the socio-material nature of these themes, we believe IS research is a natural fit for the area. First IS research of this kind is emerging only recently. For instance, Qin, Yuan, and Wang (2019) study reward mechanisms in proof-of-work mining pools.

2.2 Interactions between Blockchain Protocol Level and Blockchain Application Level

Second, there are important interactions between the protocol level and the application level. Different blockchain protocols constrain and afford different applications and uses (Glaser, 2017). For example, private blockchains may be better suited for supporting the operations of incumbent players such as governments and established companies, given their higher degree of centralized control and confidentiality. However, not only the blockchain protocol itself, but also the imbrication of human agents and the blockchain protocol constrains and affords applications. For instance, if one agent accumulates a lot of decision-making power in the consensus protocol, the blockchain's integrity is at stake and any blockchain application is at risk. Vice versa, the protocol level is shaped by the application level, as concerns about applicability or developments at the application level lead to changes at the protocol level. These changes can either take the form of modifications of human agent behavior or modifications to the blockchain protocol. There are examples for both instances: For the former, high demand for Bitcoin and, therefore, high prices

incentivized agents to participate in the consensus protocol to earn mining rewards.⁴ For the latter, concerns about limited throughput led to several Bitcoin forks, where groups of developers set up alternatives to Bitcoin by changing the Bitcoin protocol to allow for increased scalability (Andersen & Ingram Bogusz, 2019). Overall, refocusing IS blockchain research on the interactions between the protocol level and the application level might allow for a richer understanding of the blockchain phenomenon. For example, a recent paper (Pedersen, Risius, & Beck, 2019) discusses not only in which application contexts it makes sense to use a blockchain, but also clarifies which blockchain to use in which context.

2.3 The Blockchain Application Level

Most IS research on blockchain has thus far focused on the application level, which concerns how blockchain can be applied to business problems or societal issues. Many proposed blockchain applications are based on the idea of using smart contracts, which are not unique to blockchain (Halaburda, 2018). At the same time, many believe that smart contracts, when paired with blockchain, may be particularly beneficial, by leading to outcomes such as disintermediation (Clemons et al., 2017). The other salient application area of blockchain is cryptocurrencies. It should be noted that cryptocurrencies play a role both at the protocol level and the application level, depending on the context. For instance, cryptocurrencies are a protocol-level issue if the focus lies on analyzing how they incentivize agents' participation in the consensus protocol. However, cryptocurrencies can also be an application-level concern; for instance, if one is concerned with whether users perceive them as a currency or as an asset.⁵ Another important aspect is that the application level is socio-material, akin to the protocol level, since at the application level we find a range of technological artifacts (e.g., smart contracts) embedded in a social context. However, the focus of our framework lies on the protocol level and its interactions with the application level and, therefore, the framework does not further elaborate on the application level.

Nevertheless, research on blockchain applications is indeed important—in particular, for understanding the consequences of blockchain's use. Claims that the advent of blockchain and blockchain-based smart contracts may have substantial implications for trust (Beck, Czepluch, Lollike, & Malone, 2016), transaction costs, and intermediaries (Catalini &

⁴ <https://www.coindesk.com/bitcoins-price-surge-is-making-hobby-mining-profitable-again>

⁵ Glaser, Zimmermann, Haferkorn, Weber, and Siering (2014) investigate whether users perceive Bitcoin as a currency or as an investment vehicle.

Gans, 2016; Clemons et al., 2017; Iansiti & Lakhani, 2017) can be empirically assessed in application contexts. Even though IS blockchain research concerning the application level is published more frequently than research on the protocol level, there is still a need for more theory-driven and empirically rigorous work on the application level. Our argument is, therefore, not to shift the focus of IS research on blockchain away from the application level, but to go beyond the applications by also considering the protocol level, as well as interactions between the levels. Thus, this editorial offers a research agenda for blockchain research in IS that accounts for these areas. Our research agenda is inclusive, spanning the three main paradigms in IS research (behavioral, design, economics), all of which can make valuable and important contributions to further our understanding of blockchain. In the next chapter, we will provide a brief discussion of critical issues at the protocol level to serve as important cornerstones for our research agenda.

3 Critical Issues at the Blockchain Protocol Level and Their Interactions with the Blockchain Application Level

Our framework suggests several opportunities for future blockchain research within IS that take the protocol level into account, either by focusing on the protocol level exclusively or by considering the interactions between the protocol level and application level. In particular, we direct the attention of IS researchers toward issues of information privacy, scalability, security, and environmental sustainability. All of these are important because they exert affordances and constraints on blockchain applications, and are also shaped by concerns at the application level. In particular, issues of information privacy, security, and environmental sustainability are also inherently sociomaterial, which makes them potential IS research areas, even if concrete application scenarios are not taken into account.

Information privacy refers to the ability to control how an individual's personal information is acquired and used (Westin, 1967). Such concerns arise since, in most blockchains, transactions are not anonymous but pseudonymous. Transactions can be traced back to their initiator and recipient, who can be identified through their public addresses. Previous research has shown that users are often not aware of the issue (Fabian, Ermakova, & Sander, 2016), even though it has been demonstrated that it may be possible to reveal users' real-world identities (Meiklejohn et al.,

2013; Reid & Harrigan, 2013; Yin et al., 2019). To address the issue, anonymous blockchains such as Monero obfuscate their users' identities (Kumar, Fischer, Tople, & Saxena, 2017). However, such blockchains are often used for criminal purposes such as ransomware attacks and transactions on darknet marketplaces. Moreover, their privacy-preserving mechanisms can be compromised, even though countermeasures have been proposed (Möser et al., 2018).

Scalability refers to the number of transactions a blockchain can process within a given time. It is another major concern when blockchains are used. A number of ways to address the issue have been suggested (Croman et al., 2016). One way to foster blockchain scalability is to conduct transactions off-chain. It is, however, likely that the resulting performance improvements are also associated with increased centralization, and it is unclear if protocols conducting transactions off-chain can outperform blockchains such as Bitcoin's overall (Croman et al., 2016). Another often proposed approach to promoting scalability is to increase the block size so that blocks can contain a higher number of transactions. However, increasing block size may increase the number of forks and the possibilities for double-spending attacks (Karame, Androulaki, Roeschlin, Gervais, & Čapkun, 2015; Vukolic, 2015). Moreover, similar to conducting transactions off-chain, there are concerns that increasing block size might foster centralization in the consensus protocol.⁶ The example of Steemit, a blockchain-based social network, illustrates how decentralization is sacrificed for scalability (Ciriello et al., 2018).

Such a trade-off may impede *security* since the blockchain's integrity, and thus its tamper-resistance, is contingent on decentralization of decision-making power in the consensus protocol (as discussed in Section 2.1). Agents with a high degree of decision-making power in the consensus protocol could attack the blockchain by double-spending cryptocurrency, effectively spending more than they own (Gervais et al., 2016). However, attacks on consensus protocols do not necessarily have to be motivated by profit. Such *Goldfinger attacks* can be motivated by political or social aims (Kroll, Davey, & Felten, 2013). Strategies for obtaining decision-making power in consensus protocols can also vary. For instance, given that computing power does not have to be bought but can also be rented, it might be less costly to compromise blockchains relying on proof-of-work consensus protocols than is often assumed (Bonneau, 2018). Besides matters of centralization in the consensus protocol, other security issues are also

⁶ <https://cointelegraph.com/bitcoin-cash-for-beginners/what-is-bitcoin-cash#story-of-the-hard-fork>

important. For example, distributed denial-of-service (DDoS) attacks occur frequently (Vasek, Thornton, & Moore, 2014). Blockchain-based smart contracts are also affected by security issues—in particular, given that coding errors could have major consequences (Beck et al., 2018).

Consensus protocols are also of importance due to issues of *environmental sustainability*.⁷ Proof-of-work, still the most prominent consensus mechanism, assigns the right to add a new block to the blockchain based on the expenditure of computing power (Nakamoto, 2008). In practice, this has led to an arms race with ever-expanding energy consumption. Alternative consensus mechanisms, including proof-of-stake and delegated proof-of-stake, address these concerns. Proof-of-stake averts the issue by assigning the right to validate a new block based on the amount of cryptocurrency (the “stake”) an agent owns (King & Nadal, 2012). In delegated proof-of-stake, a consensus mechanism for permissioned blockchains (see also Table 1), stakeholders elect delegates—which are expected to behave nonmaliciously—to validate new blocks (Zheng, Xie, Dai, Chen, & Wang, 2017). While these alternatives to proof-of-work are becoming more prominent, they may not be as secure. For instance, the “nothing-at-stake” problem could impede consensus, given that there is no opportunity cost for adding new blocks to every potential fork (Bano et al., 2017). However, recent research suggests a key assumption underlying the notion of the “nothing-at-stake” problem may not hold (Saleh, 2018). Moreover, ways to address the problem are being devised, and major blockchains such as Ethereum plan to migrate from proof-of-work to proof-of-stake in the future (Buterin & Griffith, 2017).

A review of applications in practice illustrates trade-offs are indeed occurring between scalability, security, and environmental sustainability. For instance, Bitcoin appears to be rather secure, but it is neither scalable nor environmentally sustainable, with a maximum transaction processing capacity range estimated at between 3.3 and 7 transactions per second (Croman et al., 2016) and an energy consumption that may rival Denmark’s.⁸

Since the socio-material nature of the issues identified at the protocol level aligns with our discipline’s focus on socio-material phenomena, we believe that IS research could contribute to studying these important trade-offs. Moreover, a better understanding of the interplay between blockchain applications and blockchain protocol is needed, given that issues of privacy, scalability, security, and environmental sustainability exert constraints on how blockchains can be used for applications. Vice versa, decisions about design trade-offs at the protocol level are contingent on the applications the respective blockchain is used for. For example, it has been argued that in the case of Steemit, which relies on delegated proof-of-stake, it may be acceptable to compromise security for scalability, since most value transfers are microtransactions.⁹ In the next section, we provide concrete ways for IS researchers from the discipline’s three major paradigms to address such concerns, in addition to other issues that are exclusively situated at the protocol level or application level.

4 An Agenda for Blockchain Research in Information Systems

The advent of blockchain opens up intriguing opportunities for research within and across the blockchain protocol and application levels. New theories are needed to address all kinds of important questions blockchain gives rise to. To lay the foundations for theory development, new frameworks are necessary to understand key concerns of IS research on blockchain. Such work would support the development of theories that further our understanding of blockchain as well as its impacts. Rigorous empirical research is needed to test these novel theories and to test existing theories that should be revisited in light of blockchain. In the following subsections, we articulate a cross-cutting future IS research agenda on blockchain that directs attention toward opportunities for research on blockchain situated in the behavioral, design, and economics research paradigms.

⁷ In this discussion, we focus on negative environmental impacts of blockchain. It has been argued that blockchain may be useful to foster environmental sustainability (Chapron 2017). This is, however, not a primary issue for the blockchain protocol level, but for the application level.

⁸ https://www.washingtonpost.com/news/worldviews/wp/2018/02/13/cryptocurrency-mining-in-iceland-is-using-so-much-energy-the-electricity-may-run-out/?noredirect=on&utm_term=.bd1b0026be6b

⁹ <https://medium.com/loom-network/scalability-tradeoffs-why-the-ethereum-killer-hasnt-arrived-yet-8f60a88e46c0>

Table 2. Agenda for Behavioral IS Research on Blockchain

Blockchain level	Possible areas of inquiry
Protocol level	<ul style="list-style-type: none"> • What is the role of trust that individuals place in the blockchain system? • How can we explain actors' propensity to pursue Goldfinger attacks? • What motivates actors to participate in transaction validation? • How are forks in the blockchain protocol initiated at the social level? • What are the mechanisms of the interplay between consensus at the social level and in the blockchain protocol? • How are blockchain-based decentralized autonomous organizations governed? • How are decision rights allocated? • What are the forces that drive (de)centralization of decision rights? • Is blockchain changing how accountability is enacted?
Interactions between protocol level and application level	<ul style="list-style-type: none"> • How do concerns about applicability shape how the blockchain protocol is negotiated? • How can application users actualize blockchain's affordances? • How do constraints imposed by the blockchain protocol affect user behavior? • How do application users change their behavior in the light of openly available (albeit pseudonymous) data trails in public blockchains? • How does user behavior vary between blockchains that enable pseudonymous transactions versus blockchains that enable anonymous transactions? • How do concerns about security impact user behavior?
Application level	<ul style="list-style-type: none"> • How does the use of blockchain affect actors' behavior in the light of de facto immutability of data? • How can we explain blockchain adoption?

4.1 A Blockchain Research Agenda for Behavioral Information Systems Research

Behavioral (individual, group, and organizational) IS research on blockchain has the capacity to make contributions across all levels of our framework (see Table 2). At the protocol level, the advent of blockchain raises issues of trust. While it has been argued that blockchains reduce the need for trust, it seems likely that at the protocol level, actors using the blockchain for applications need to trust both the algorithms that make up the actual blockchain protocol as well as the agents managing the network. The protocol itself may contain bugs which even expert developers might fail to detect, whereas the agents may have malicious intent. However, the role of trust that individuals place in the blockchain is still little understood, and research studying the issue of trust in blockchain is much needed. Such research is linked to issues of security. Typically, it is assumed that agents attacking the blockchain's integrity are profit seeking, but the motives agents may have for attempting Goldfinger attacks are little understood (see also Bonneau, 2018). Similarly, it is mostly assumed that agents participating in transaction validation are motivated by profit. However, other

motives may also play a role. Understanding these factors might be useful for ultimately designing blockchain protocols that are made more secure by ensuring incentive alignment. At the protocol level, governance issues are particularly interesting (see Beck et al., 2018, for a blockchain governance framework and research agenda). Even though many expect blockchain-based organizations known as decentralized autonomous organizations (DAOs) to change organizational governance by decentralizing decision rights, these changes have only partly materialized (Beck et al., 2018). However, in the case of consensus protocols, it is already apparent that governance has become decentralized or at least decentralizable (Andersen & Ingram Bogusz, 2019; Beck et al., 2018; Halaburda & Mueller-Bloch, 2019; Hsieh, Vergne, Anderson, Lakhani, & Reitzig, 2018). We believe more empirical research is needed to reveal how decentralized blockchains really are at this point and to study the forces that affect the degree of decentralization. This pertains, in particular, to decisions directly mediated by the consensus protocol, which concern both the transactions added to the blockchain and the blockchain protocol itself. For instance, Bitcoin is notorious for its centralized consensus protocol, which poses a substantial risk to the integrity of its blockchain and also controverts its

ideology of decentralization.¹⁰ The distribution of decision rights in the social world—for instance, at conferences, online forums, or within groups of blockchain developers—should also be studied further, given the hope that decision rights will be widely decentralized. Another important issue is accountability. Blockchain-based smart contracts may enact accountability technologically instead of institutionally (Beck et al., 2018), but more empirical research is needed to follow up on how the initial promises materialize in practice.

Behavioral IS research can also contribute to a better understanding of the interactions between the blockchain protocol level and application level. Again, governance issues are of importance here. Many decisions about the blockchain protocol are shaped by concerns about applicability, as the case of Bitcoin illustrates (Andersen & Ingram Bogusz, 2019), but more empirical research is needed to study how these decisions are negotiated and eventually made. Another important question is how those using blockchain actualize its affordances. Initial research is emerging, but the replication required for different contexts and statistical validation is still lacking (Du, Pan, Leidner, & Ying, 2018). In addition, more research is needed to study how constraints imposed by the blockchain protocol affect the behavior of individual application users. In this context, privacy is an important issue. For public blockchains, users' will leave openly available data trails, and more research is needed to understand how this affects their

behavior. In particular, changes could be expected for pseudonymous (as opposed to anonymous) blockchains. Another promising direction for future research would be to focus on how individual behavior varies between blockchains that enable pseudonymous transactions versus those that enable anonymous transactions. Overall, a more refined understanding of privacy issues is much needed and, similarly, more research is needed to better understand and explain issues associated with security, given that concerns about security are likely to shape user behavior.

At the application level, interesting questions emerge about how individual behavior changes in light of de facto immutable data (note that this is different from openly available data). While individuals are likely to become more cautious, IS research is needed to better understand how de facto immutable data affect user willingness to engage in transactions on the blockchain. Another important issue is blockchain adoption. Many promising blockchain applications have been proposed, but widespread adoption is rare (Iansiti & Lakhani, 2017). Future IS research could study the antecedents of blockchain adoption and thus contribute to addressing the adoption issue. We believe regulatory concerns may play an important role, but other factors such as protocol issues (in particular, privacy, security, and scalability) are likely also important. Research on this topic could attempt to reveal these factors, thereby contributing not only academically but also informing practice.

Table 3. Agenda for Design Science Research on Blockchain

Blockchain level	Possible areas of inquiry
Protocol level	<ul style="list-style-type: none"> • How can IS research contribute to designing more environmentally sustainable yet secure consensus protocols? • What are promising methods for designing consensus protocols?
Interactions between protocol level and application level	<ul style="list-style-type: none"> • What are the implications of blockchain protocol design choices for blockchain applications? • What are promising application areas for blockchain and what are the implications for protocol design in terms of design requirements? • Are the design assumptions behind new transaction platforms sound? • Can we understand and mitigate unintended side effects of new blockchain implementations?
Application level	<ul style="list-style-type: none"> • How can we mitigate the risk of coding errors in blockchain-based smart contracts? • How can we ensure that oracles provide correct information? • What kinds of issues arise when oracles (e.g., sensors and other IoT devices) feed blockchains?

¹⁰ <https://www.ccn.com/bitmain-mining-pools-now-control-nearly-51-percent-of-the-bitcoin-hashrate>

4.2 A Blockchain Research Agenda for Design Science Research

Blockchain also creates opportunities for IS researchers focusing on design aspects, which cut across all levels of our research framework (see Table 3). At the protocol level, the key concern is the security of consensus protocols, as well as associated trade-offs with scalability and environmental sustainability. In their current form, consensus protocols such as proof-of-work or proof-of-stake suffer from severe drawbacks. Design-oriented IS research could address these issues. Thus far, design-oriented research in this area has mainly come from computer science, but we believe that design science researchers within IS could make valuable contributions as well. They could design and evaluate alternative consensus protocols that are not only technically viable, but also strongly focused on human aspects. For instance, such design research could incorporate insights from IS economics research regarding agents' incentives and insights from behavioral IS research concerning agents' behavior beyond utility maximization. Both may be critical in ensuring the security of consensus protocols, and design-oriented IS research is well poised to study them. Related to such research, IS design researchers could also contribute by developing methods for designing consensus protocols that take human motives into account.

In terms of the interactions between protocol level and application level, several important issues can be addressed by design-oriented IS research. More studies are needed to better understand the implications of different protocol design choices for blockchain applications. Some have argued that blockchain is a solution in search for a problem¹¹. To address these concerns, another approach to identify promising application areas could be to start with a problem, by reflecting upon salient business challenges and important societal issues. Only after identifying such a problem, the researcher would identify the constraints exerted by the protocol level and propose designs addressing them. As blockchain affects established patterns of user behavior in sensitive areas—such as changing ownership of goods and monetary transactions—it is important to conduct trials in different kinds of settings and with different prototypes. This would naturally lead into using design research (e.g., Action Design Research) that promotes testing designs in real-world settings and evolving the

artifacts during their testing (Lindman, Rossi, and Tuunainen 2017). Different blockchains such as Ethereum, Hyperledger, and others, afford different things and thus restrict the choices of application developers and the use cases available. These affordances and constraints are crucial for third parties that implement new services on top of the blockchain protocol level. Critical analysis and evaluations of these platforms should result in design principles and design theories for future blockchain applications. For example, overly naive assumptions about the behavior of different stakeholders can lead to security issues or bad governance, as in the case of the Quadriga exchange founder's death and the disappearing of nearly all of clients' deposits, which will erode the trust in the blockchain infrastructures¹².

At the application level, a promising research area is the design of blockchain-based smart contracts. Smart contracts carry great potential but have thus far failed to live up to these promises. A major reason may be that blockchain-based smart contracts' advantages come at a substantial cost. If smart contracts are de facto immutable and autonomously executed, coding errors can lead to major consequences (Beck et al., 2018). Therefore, research is needed to design mechanisms that mitigate this risk and study how smart contract design can avoid logical errors and software bugs in the first place. Another important issue that design-oriented IS research should address is blockchain oracles. Oracles are needed when a smart contract stipulates that the execution of a transaction depends on a real-world occurrence. In such cases, oracles feed the information (stemming from either the digital or the physical realm—sensor data in the latter case) regarding the conditional event onto the blockchain (Xu et al., 2016). This can, however, be a problem, given that the information may be fraudulent or simply incorrect. Initial research proposing ways to address the problem is emerging (e.g., Chanson, Bogner, Bilgeri, Fleisch, & Wortmann in this special issue), but more studies are needed to further design and evaluate artifacts that can mitigate the issue.

¹¹

<https://www.forbes.com/sites/jasonbloomberg/2017/05/31/eight-reasons-to-be-skeptical-about-blockchain/>

¹² <https://www.npr.org/2019/03/06/700651500/crypto-mystery-quadrigas-wallets-are-empty-putting-fate-of-137-million-in-doubt>

Table 4. Agenda for Economics of IS Research on Blockchain

Blockchain level	Possible areas of inquiry
Protocol level	<ul style="list-style-type: none"> • How can we explain agent behavior in consensus protocols? • What are security issues and associated tradeoffs in consensus protocols?
Interactions between protocol level and application level	<ul style="list-style-type: none"> • How do different blockchain protocols create different logics of value creation and value capture? • How do changes on the blockchain protocol level affect cryptocurrency prices?
Application level	<ul style="list-style-type: none"> • How does blockchain affect the cost of doing business? • How does blockchain affect intermediaries? • What are the antecedents, consequences, and boundary conditions of the economic changes ascribed to blockchain? • What is the role of network effects in blockchains? • How do different blockchains compete? • What can we learn about initial coin offerings (ICOs)?

4.3 A Blockchain Research Agenda for the Economics of Information Systems

For those studying the economics of IS, the advent of blockchain gives rise to multiple fascinating research questions across all dimensions of our framework (see Table 4). At the protocol level, incentive alignment is crucial to ensure secure consensus mechanisms (Beck et al., 2018). Future IS research could draw from game theory to better understand how incentives structures impact agent behavior and thus security in consensus mechanisms, as well as associated trade-offs with environmental and performance concerns. Research along these lines is already emerging: For instance, Cong, He, and Li (2018) study centralization and decentralization forces in proof-of-work consensus mechanisms and argue that risk-sharing drives centralization in mining pools. They also present evidence consistent with their theoretical argument. Saleh (2018) focuses on trade-offs between environmental sustainability and security by focusing on the viability of the proof-of-stake consensus mechanisms as a sustainable alternative to proof-of-work. The paper introduces a formal economic model of proof-of-stake that demonstrates the invalidity of the “nothing-at-stake” problem. Overall, more research is needed, given that consensus protocols are still frequently being undermined.¹³

Regarding the interplay of protocol level and application level, IS research could investigate how different blockchain protocols create different logics of value creation and value capture. Initial research on this is already emerging (Hua, Chong, Lim, Zheng, and

Tan in this special issue), but, in particular, the role of the blockchain protocol level deserves further attention. In particular, it has been argued that blockchains are associated with disintermediation, however, this most likely depends on the blockchain protocol that has been implemented—private blockchains are unlikely to be associated with removal of trusted third parties.

At the application level, there are intriguing opportunities to study the nature of a blockchain-based economy. Such a *blockchain economy* (Beck et al., 2018; Berg, Davidson, & Potts, 2017) would rely on blockchain—for purposes such as payments or for record keeping in general—and possibly blockchain-based smart contracts as well. It has been argued that such an economic system reduces the need for intermediaries (e.g., Iansiti & Lakhani, 2017) and lowers costs of doing business (e.g., the cost of verification and cost of networking) (Catalini & Gans, 2016). However, more empirical evidence is needed to test these hypotheses. Moreover, the theoretical arguments need to be refined—in particular, with respect to their antecedents and consequences. Another concern is the boundary conditions of these emerging theories. Even if it can be demonstrated that blockchain has effects such as disintermediation, this will likely not be the case under all circumstances. Blockchain adoption is another important issue situated at the application level. Network effects may be a decisive factor determining the adoption and competition of blockchains. First evidence shows that network effects and winner-take-all dynamics drive competition between blockchains (Gandal & Halaburda, 2016), but more research is needed to expand on these findings, particularly regarding how

¹³ <https://cryptoslate.com/ethereum-classics-51-percent-attack-highlights-challenges-proof-work-coins/>

competition evolves over time. Studying the switching costs associated with blockchains would be of particular interest in this context. Another emerging area of research is initial coin offerings (ICOs). For instance, Bruckner, Steininger, Veit, and Thatcher (2019) analyze what influences investments in ICOs. Other research shows that the platform-specific tokens issued in ICOs can help to address the coordination problem in network adoption (Bakos & Halaburda, 2018). IS researchers could get more involved in understanding and explaining different facets of ICOs, and these papers provide a useful starting point for research on the topic.

5 Concluding Remarks

Besides computer science and cryptography studies, blockchain has been predominantly discussed in the practitioner literature. Rigorous empirical and theory-driven IS research on blockchain is emerging gradually. Our special issue contributes to this new area of inquiry. This editorial reviews and expands on existing IS research on blockchain by providing a framework for blockchain research in IS that directs attention to two important issues: First, the need for IS research to consider the blockchain protocol level, which is characterized by recursive interactions

between human agents and the blockchain protocol. Second, the lack of IS research that considers how the protocol level constrains and affords blockchain applications, and how these constraints and other issues at the application level lead to changes at the protocol level. We propose an inclusive IS research agenda that emphasizes the need for behavioral (individual, group, and organizational), design science and IS economics research on blockchain. IS scholars conducting such research can contribute in several meaningful ways: by developing a thorough theoretical understanding of the blockchain phenomenon, by testing these theories through rigorous empirical research, and by communicating research findings to practice.

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