Imaginaries and Crystallization Processes in Bitcoin Infrastructuring

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Abstract. Imaginaries is a concept from Neumann and Star that signifies 'points of understanding' of the various stakeholder visions of an infrastructuring project. Stakeholders use imaginaries to negotiate their differences and identify shared visions. The ways in which these stakeholders negotiate these differences to agree on concrete artifacts and practices is known as crystallization. However, the CSCW literature has not studied crystallization in detail. Our case study examines imaginaries and crystallization within the infrastructuring of Bitcoin, an open source digital currency and payment platform that is the first of emerging forms of peer-to-peer computer networks facilitating digital transactions. We conducted participant observation of two Bitcoin conferences held in December 2015. Each conference lasted between two to three days, amounting to 40 hours of observation. In these conferences, we examined Bitcoin infrastructuring taking place across different contexts, including open source development and startup communities. Each of these contexts contains pre-existing infrastructures along with powerful gatekeepers (e.g., software committers and financial regulators) who maintain its system of practices and artifacts. The Bitcoin actors, including open source developers and entrepreneurs, make use of imaginaries to identify differences among them, negotiate, and reach points of crystallization in order to integrate with these infrastructures. Based on these findings, we contribute the concept of imaginaries branching and discuss roles of imaginaries in an expansive infrastructuring work interacting with multiple installed bases, some of which also introduce practical limits to the imagined information system.

Keywords: Bitcoin, Blockchain, Crystallization, Imaginaries, Infrastructuring

1. Introduction

Infrastructuring is a process in which its stakeholders appropriate computing systems, social practices, and user bases to develop them into an infrastructure (Bowker and Star 1998; Evans and Schmalensee 2004; Neumann and Star 1996; Pipek and Wulf 2009). One of the key challenges in infrastructuring is that it is difficult for a large number of stakeholders to agree on a shared vision of the eventual infrastructure. The reason is that infrastructuring rarely begins with a grand design vision, but rather, each stakeholder may only be building a small part of the entire system and only in a way that supports her vision of what she imagined the infrastructure will become. And when each designer attempts to realize her own vision, the whole infrastructuring work will inevitably encounter co-ordination and compatibility issues. Thus, Neumann and Star (1996) proposed that we examine *imaginaries*—or a multiplicity of visions of the collective of stakeholders and of the future of the infrastructure. In particular, they argued that imaginaries are links which stakeholders can use to communicate with one other to come to agree on standards and shared practices.

While imaginaries help stakeholders describe and communicate each of their own visions, how these stakeholders come to mutual agreement has not been closely examined. This use of imaginaries has been described as a process of communication and negotiation until *crystallization*, a point at which stakeholders realize what the constraints are among these different stakeholders and gain clarity of what the infrastructure should be (Neumann and Star 1996). CSCW research also emphasizes the resolution of significant misalignment of work in infrastructuring—that infrastructures occur when the tension between local and global, as well as short-term and long-term, are resolved (Karasti et al. 2010; Star and Ruhleder 1996). Existing studies examining imaginaries and crystallization have mostly focused on smaller scale infrastructuring work (e.g., digital library development) (Neumann and Star 1996). There are many unanswered questions about crystallization in the context of larger scale infrastructuring work: does it involve crystallization processes beyond negotiation? If so, what methods do stakeholders employ to converge on a set of shared visions? And what happens to stakeholders who cannot agree on the shared vision of the majority of the stakeholders? What roles do gatekeepers play in crystallization, and how do their roles differ from those of stakeholders with less agency?

Bitcoin is an open source digital currency and payment platform, the first of emerging forms of peer-to-peer networks facilitating digital transactions. In this study, we looked at the imaginaries and crystallization in the infrastructuring process of Bitcoin, by conducting participant observation of two Bitcoin conferences held in December 2015. One of these conferences centered on negotiations among a group of Bitcoin's open source developers discussing parameters of Bitcoin's design. The other conference centered on entrepreneurs, legal professionals, investors, and technologists to share their plans, experiences, and visions for the industry (see Jabbar and Bjorn 2017). We found complementary imaginaries as well as conflicting imaginaries within their discourses. The two conferences, focused on two overlapping groups of attendees, showed the ways imaginaries can spread and shift across linked contexts; and how disagreements within each context help drive imaginaries and infrastructuring in distinct directions.

2. Imaginaries and Crystallization in Infrastructuring

In infrastructuring, the importance of concepts such as *imaginaries* and *crystallization* originated from the way *infrastructuring* is different from *design*—infrastructuring often involves a large number of stakeholders with a wide range of motivations, purposes, practices, and constraints (Pipek and Wulf 2009). Importantly, unlike design work which normally serves a known market of users, infrastructuring work often only serves an imagined group of future users who do not yet exist (Neumann and Star 1996). Thus, while design teams could perform user research or market analysis to determine which design solution would generate the most value for its users (Andriopoulos and Lewis 2008; Austin et al. 2011) there are few objective measures that stakeholders in infrastructuring can utilize to identify the best course of action. Without users, there is no profit to speak of, and no stakeholder value measure which can be used to baseline performance. When a stakeholder believes his design could serve a projected social group, other stakeholders may disagree. Furthermore, there is no standard 'information processing practice' in infrastructuring that everyone can agree on as an authoritative measure of a 'good design'; the infrastructuring work is supposed to come up with such practices (Bowker and Star 2000).

Thus, *imaginaries* became an important concept in clarifying possible features of infrastructure, and by which different stakeholders can conduct negotiation, such as to define technical and service standards, and even whom the infrastructure ought to serve (Bowker and Star 1998, 2000; Pipek and Wulf 2009). An example of a difficult infrastructuring process was given by Neumann and Star (1996). They described how the software development of a digital library was halted while waiting for a journal publisher to agree to digitize their library; in turn, the publisher was waiting for the library's developer to complete milestones before it was willing to publish those journals in digital formats. Thus, although the developer and the journal were both working on pieces of this emerging digital library infrastructure, they had contradictory expectations of the deliverable and timeline. In such a work structure, careful negotiation and construction of complementary visions among stakeholders become important tools for successfully creating new infrastructure (Constantinides and Barrett 2014; Neumann and Star 1996).

According to Neumann and Star (1996), imaginaries tend to be abstract, such as a vision statement or a story. Note that *imaginaries* is used differently from forms of thinking such as daydreaming and fantasizing (Murphy 2004). Imaginaries have a social purpose of enhancing communication within large-scale collaboration. In infrastructuring, stakeholders of different backgrounds may use different nomenclatures and decision making processes (Neumann and Star 1996). Thus, it is important for these stakeholders to express their visions in ways which are minimally technical, and also descriptive and accessible to all stakeholders (Neumann and Star 1996). For example, Murphy (2004) describes how architects often spend considerable time elaborating shared imaginations of a building site in order to coordinate collaborative work,

> 'Imagining is a social and embodied activity that is supported by material objects, mediated by gestures, initiated by conversation, and maintained through the external force of all of these things as they are simultaneously employed in imagining while interacting with other social beings.' (p. 269)

Imaginaries help stakeholders (e.g., developers, entrepreneurs, and network providers) of different social and institutional backgrounds translate their visions into socially intelligible forms. Imaginaries help a group of people agree on verbiage, images, and visions of a hypothetical scenario, and serve as a basis for working together towards 'some consequential purposes' (Murphy 2004, p. 277).

According to Neumann and Star (1996), an imaginary can contain elements that help answer three questions facing stakeholders: one, an imaginary may express the reasons why a stakeholder chose to get involved in an infrastructuring work, and under what circumstances he would continue to remain committed to the project. For example, a developer may want to create a profitable Bitcoin-based crowdsourcing system. By sharing her commitment, this developer can attract funding or partners who are also interested in anonymous systems. Two, an imaginary may elaborate each stakeholder's own standards and practices, so that the other stakeholders can learn how to work with them. For example, to attract startups to work with investors, an investor can narrate stories of how he had judged the potentials of previously successful startups. Three, an imaginary may contain a trajectory, or timeline, so that other stakeholders can negotiate a development schedule. For example, the above investor could lay out a funding schedule which entrepreneurs could work around or even use in negotiations.

In addition, imaginaries could also envision user bases. According to Ribes and Finholt (2007), 'The most pervasive concern within funding agencies, amongst designers and for future users is not of breakdown, but in the failure to receive adoption. Beautiful but empty informational corridors are not infrastructure at all' (p. 9). Therefore, imaginaries should not merely be a list of commitments, standards, or timelines, but also include dreams of people's future practices within the *infrastructure*; that is, how users will use the new artifacts and live with them (Bowker and Star 1998; Pipek and Wulf 2009; Resnick et al. 2011).

Through imaginaries, stakeholders have a medium to negotiate standards, practices, and user bases of the infrastructure. And this standardization often occurs after *crystallization*, a process in which stakeholders, through a period of imaginaries sharing, gain clarity of what the infrastructure should be, as Neumann and Star (1996) describe,

> 'Trajectories of work and decision making come together in a crystallization point and then move on from there… With consensus, display, compatibility, time investment, and an agenda for further work will be crystallized. The difficulty is in predicting and coordinating these crystallization points.' (p. 238)

In this description, Neumann and Star suggest that it is difficult to predict when stakeholders will come to agreement with each other, and it is a challenge for stakeholders to contend with this unpredictability. They use the concept of crystallization to describe this moment of agreement.

According to Neumann and Star (1996), working towards crystallization involves two phases. In the first phase, the stakeholders communicate to one another and realize which part of their design is not feasible. In the second phase, each stakeholder determines if they want to reconsider their design, and how to do so. As a result, between communicating imaginaries and crystallization, stakeholders have to engage in an involving process of identifying what their constraints are—both imposed by their own environment as well as by the other stakeholders (Neumann and Star 1996). Then the stakeholders have to be involved in a process of negotiation until a point where each person's commitments, shared technical standards and practice, and development trajectories become clear.

Beyond this outline of the crystallization process, there remains a limited understanding of how imaginaries and crystallization processes function in a large-scale infrastructuring project. Since Neumann and Star (1996) used the terms *imaginaries* and *crystallization* in their study of a relatively small digital library development project, they questioned how stakeholders could find the right language to communicate in a large-scale infrastructuring project with interdependencies across multiple institutions. And how could the stakeholders find ways to connect their infrastructuring work to other existing infrastructures?

In the following sections, we will examine ways that stakeholders negotiate differences caused by conflicting imaginaries and how they lead to crystallization points in the case of Bitcoin.

3. Bitcoin as a Large-Scale Infrastructuring Project

In this section, we describe the recent history of Bitcoin infrastructuring between 2008 and 2016. Initially, Bitcoin was developed as a digital monetary system which can function without institutional intermediaries; it attracted many libertarian developers due to their general distrust of the government. Since 2012, Bitcoin's ability to eliminate intermediaries has generated interest from businesses wanting to trade currencies, derivatives, and other digital assets more efficiently. Thus, early development of the peer-to-peer networks by libertarians has paved the way for companies to imagine new business concepts, such as a stock exchange without the need for clearinghouses. As companies experiment with novel services, Bitcoin's developers are still coming up with new features for Bitcoin, leading to a dynamic infrastructuring field.

3.1. Bitcoin's Libertarian Founding

In 2008, Satoshi Nakamoto (2008) first introduced the white paper 'Bitcoin: A Peer-to-Peer Electronic Cash System'; and in 2009, Nakamoto shared Bitcoin as an open source software. The true identity of Satoshi Nakamoto is a mystery, and it has been suggested that Nakamoto may either be a group of people working together or perhaps one of the cryptographers who had written about related ideas.

Bitcoin's design was originally motivated by imaginations of utopian online societies (i.e., libertarianism) (see May 2001). In these societies, anyone can trade freely with anybody they like; anyone can buy or sell anything they like; if a trade is illegal, the traders need not fear because they are anonymized by cryptography, and they need not meet the other party in person. Contrary to popular notions, such imaginations were not born out of criminal intent, but from the 'cypherpunk' culture dedicated to freedom from increased institutionalization (Coleman and Golub 2008). This ideal, conveyed in the community as the technical requirement of the system being 'trustless,' signifies automated peer-to-peer processes without the need to depend on human intermediaries in order to function (Khairuddin et al. 2016). In other words, social activities within this utopia are governed by software code alone. While many financial actors will deem this an impossible dream (Reijers and Coeckelbergh 2016), such motivations have already given rise to many influential innovations such as public key encryption and virtual currencies prior to the creation of Bitcoin. Thus, Bitcoin can be seen as the latest form of a series of endeavors to improve online anonymity, and to increase the effectiveness and efficiency of online anonymous transactions (see Jasanoff and Kim 2015).

In Bitcoin, Nakamoto managed to create a monetary system that eliminates certain needs for trusted third parties by utilizing a peer-to-peer network for verifying transactions. The Bitcoin network verifies transactions by allowing peer computers to validate transactions against its public and pseudonymous ledger which Nakamoto called a *blockchain* (Maxwell et al. 2015). Note that we adopt a nomenclature among Bitcoin developers and some early users, which uses *Bitcoin* ('B' in uppercase) to represent the digital network and its blockchain, and *bitcoin* ('b' in lowercase) for the digital money itself. In order to incentivize more users to support this validation process, users who contribute computing power to run the validation software receive a random chance of being rewarded with newly generated bitcoins. This method of issuing newly minted bitcoins is known as bitcoin *mining*, and actors who engage in mining are known as *miners*. This design of the Bitcoin's peer-to-peer system was appealing to libertarians, who made up nearly 60 percent of Bitcoin's early adopters (Lustig and Nardi 2015).

3.2. Bitcoin's Infrastructuring and New Actors

Starting in 2012, Bitcoin went from a currency favored by libertarians into an emergent technology increasingly explored by businesses. While Bitcoin's blockchain was the first, many blockchains now exist. For example, other developers have proposed alternate blockchain designs such as Ethereum and Hyper Ledger (Khalid 2017). These designs allow open source communities and companies to develop more comprehensive products and services, such as cloud-based services and other peer-to-peer applications beyond simple digital currency transfer (Higgins 2015; Khalid 2017). Among the institutions to take part in Ethereum and Hyper Ledger development include Cisco, IBM, Intel, SAP, Microsoft, and J.P. Morgan (Hackett 2017; Hyperledger 2017). And entrepreneurs and venture capitalists within the community are actively identifying potential markets for Bitcoin such as real estate (Higgins 2015), insurance (Wong 2015), and payroll management (e.g., Bitwage).

Due to these developments, much of the discussion in the Bitcoin community has also foregrounded potentials of Bitcoin as a blockchain rather than merely bitcoin as a digital currency. The relationships between Bitcoin and the emerging blockchains are historically linked, and at the events we attended, it was impossible for participants to discuss Bitcoin without comparing it with the other blockchains. Thus, when we refer to all of these activities as a collective, we use the term 'Bitcoin infrastructuring.' We use the term 'Bitcoin blockchain' when referring to the first and subsequent versions of the open source software developed by Nakamoto; and we use the term 'blockchains' to refer to all the different kinds of blockchains collectively.

Despite these promising developments, many aspects of the Bitcoin software are still being defined. And Bitcoin actors are still discovering and working to resolve newfound limitations with governance structure, poorly defined markets, and the law. By interviewing participants, and observing and analyzing their discourses, we can examine these issues faced by the emerging infrastructure.

3.3. A Participant Observation Study Investigating Negotiation among Bitcoin Developers and Business Actors

We conducted this research as part of a larger project to examine Bitcoin activities globally in order to understand the technology's long-term implications to users, developers, and businesses. Prior to this study, both the first and second authors had kept track of Bitcoin activities on online forums (e.g., bitcointalk.org) and Reddit (e.g., /r/bitcoin and /r/btc), and attended no less than 58 hours of conferences and Meetup meetings. In these settings, both authors conducted 43 in-depth interviews, between 2013 and 2015, in which 19 interviewees resided in the US, nine in Hong Kong, four in Singapore, three in Germany, two in Australia, two in Canada, two in China, one in Croatia, and one in Argentina. The authors have collectively published three articles based on these interviews, which have focused on users' perceptions of Bitcoin (Lustig and Nardi 2015), background and motivations of stakeholders who participated in Bitcoin development (Kow and Ding 2016), and the ways with which technologies like Bitcoin may enable new forms of peer collaboration work (Kow 2017). This article extends our previous studies by examining development constraints faced by these stakeholders, and their strategies to overcome them. In this study, we focused on and conducted participant observation of two Bitcoin conferences held in December 2015. Each conference lasted between two to three days, amounting to 40 hours of observation. Both conferences had a different focus and target audience. The first conference, *Scaling Bitcoin*, held in Hong Kong on 6–7 December 2015, was a technical conference in which Bitcoin's open source developers and miners discussed emerging Bitcoin technologies. The second conference, *Inside*

Bitcoin, held in San Diego on 14–16 December 2015, was a business conference in which entrepreneurs, legal professionals, investors, and technologists discussed business strategies in the Bitcoin industry. Both conferences provided complementary focuses that painted a larger picture of Bitcoin infrastructuring. All individual presentations and panel discussions were audio-recorded and transcribed. In addition, we took field notes to record immediate observations.

During the second Bitcoin conference in San Diego, we iteratively discussed common themes that had emerged during the participant observation process. First, we identified the way that Bitcoin infrastructuring is distributed across actors representing different parts of the industry, such as developers, miners, entrepreneurs, and lawyers. We noted the ways each of these actors were facing different issues and limitations, such as developers debating technical designs in Bitcoin. We focused our attention on the ways different speakers discussed how they were constrained by other actors of the emerging infrastructure. After the conferences, we analyzed the transcriptions and performed additional rounds of coding to classify various interactions between actors and organizations. Then, we noted how the imbalance of sociopolitical power among stakeholders was influencing negotiation outcomes. And this observation led to other concepts we are discussing in this paper. While we have mostly presented findings uncovered during both Bitcoin conferences, we have also used one quote from an incubator ('David') from our previous interviews that better describes the perspective of investors.

We have obtained ethical review clearance from our institutions to perform observations and interviews with our participants. The participants were not aware that they were being observed, but these were public events that anyone who had registered could attend, and the video recordings of the Scaling Bitcoin conference are available in the public domain. We also noted that the Scaling Bitcoin conference observed the Chatham House Rule, that 'participants are free to use the information received, but neither the identity nor the affiliation of the speaker(s), nor that of any other participant, may be revealed' (Wikipedia 2017). In general, to protect the identities of all our participants, we have replaced names of all conference attendees and their associated companies with pseudonyms, with the exception of the ex-Bitcoin lead developer ('Andresen'), a public and famous figure whose single quote used in this paper is available in the public domain.

In the following two sections, we will discuss Bitcoin imaginaries and how stakeholders worked towards crystallization through the two phases identified by Neumann and Star (1996). In section 4, we describe a difficult negotiation to resolve a conflict among Bitcoin open source developers. In section 5, we present imaginaries among a handful of commercial actors, and how they revised these imaginaries to come to terms with demands of external actors and infrastructures.

4. Negotiating Bitcoin Design: A Struggle among Stakeholders

While most developers can agree on general metaphors of a utopian online society, they can still harbor different imaginaries which contradict each other. An example of such differences came from a split between a handful of developers and its committers regarding how and when they should increase the transactional capacity of Bitcoin. Among imaginaries of Bitcoin's trustless utopia, most developers agreed that in order for the network to one day serve the large number of global users, the bandwidth of the network ('the blocksize') would need to be increased. Poon and

Dryja (2016) estimated that this would require each peer-to-peer computer node to process 400 terabytes of data a year in order to maintain a global ledger as massive as those of Visa. This means that most ordinary participants would stop hosting nodes, thus leading to fewer nodes, most likely institutional, that are able support the Bitcoin network. A majority of Bitcoin's core developers perceived that these institutional nodes would 'sacrifice the decentralization and security that the network provides,' and rigorously opposed any amount of blocksize increase (Poon and Dryja 2016, p. 2). But since April 2015, a subset of developers, including Gavin Andresen, the ex-Bitcoin development lead from 2011 to 2014, have been concerned that the infrastructuring process is moving too slowly to keep up with Bitcoin's transactional growth rate; and they advocate that the open source community needs to increase the capacity of each node quickly before Bitcoin businesses are affected. In August 2015, Andresen said,

> 'Looking at the transaction volume on the Bitcoin network, we need to address [this problem] within the next four or five months. As we get closer and closer to the limit, bad things start to happen. Networks close to capacity get congested and unreliable. If you want reliability, you'll have to start paying higher and higher fees on transactions, and there will be a point where fees get high enough that people stop using Bitcoin.' (quoted in Simonite 2015)

While Andresen imagined that a blocksize increase needed to happen right away, many core developers disagreed.

4.1. Not All Developers Are Equal: Technical Disagreement and an Uneventful Negotiation

In an open source community, any individual developers can submit proposed changes (known as a *pull request*) to the software. But only the software leads (known as *committers*) have the ability to accept the pull request and include the new code into the software. And while Andresen and others had proposed changes to the Bitcoin system, the committers opposed these changes, thus creating tension among developers.

Open source developers (e.g., of Linux) who disagree with their committers do have another option—of copying its code in its entirety and creating an entirely new project; this process is known as a *fork*. A fork would be able to resolve this tension between individuals and the group, since individuals can branch off to develop new projects. But some participants argued that creating a fork would be undesirable because they believed that it would lower the market price of Bitcoin. And if the price of Bitcoin fell, there might be less incentive for stakeholders to mine the currency, and thus fewer miners might contribute to the network. With fewer miners, Bitcoin would be less secure and its viability as a currency would be limited.

In an attempt to reconcile these differences, at the time of writing this article, the open source developers organized two *Scaling Bitcoin* workshops, in Montreal in September 2015 and then in Hong Kong in December 2015, to discuss and debate this issue. At the Hong Kong workshop, Carlos, the founder of a Bitcoin fork, explained, 'A schism hard-fork is like going to war, and we don't want to kill civilians or anything; we don't want to hurt bystanders that don't know what's going on.' A schism could greatly decrease stakeholders' trust in Bitcoin, and thus the market value and security of the network.

Instead of succumbing to pressure from developers like Andresen, the committers and a group of core developers presented alternative technical solutions, such as the *Lightning Network*, at the workshop. A technical description of the Lightning Network is beyond the scope of the paper (see Poon and Dryja 2016 for details), but a key feature of the network is that its technical design is anticipated to reduce the future requirements of a Bitcoin node so that the transactions can be handled by a home-based personal computer (Poon and Dryja 2016).

But Andresen and others have pointed out that proposals like Lightning were at least a few years away from full-scale deployment, and the Bitcoin network was already close to its transactional capacity. While the debate ensued, blockchain users, including major Bitcoin companies like Coinbase, were backing propositions to increase the blocksize directly, as opposed to waiting for alternate solutions.

4.2. Breaking the Deadlock: Miners as Reluctant Gatekeepers

While software updates can alter the design of the Bitcoin blockchain, miners have to install these updates into their computing devices in order for the changes to propagate across the network. Therefore, miners who do not agree with the developers' propositions may choose not to install the updated Bitcoin software. Miners thus act as an incidental group of gatekeepers, who largely remained silent before *Scaling Bitcoin*, but are powerful enough, by Bitcoin's design, to reject technical propositions. Until recently, it was rare for miners to reject technical propositions. As Carlos explained,

> 'People sometimes called this "miner voting," but I don't like calling it "miner voting" because it's not something that is being voted, these changes were supposed to be completely non-controversial and we expect all miners to use, so they're not really voting on anything.'

However, when faced with multiple competing proposals, miners were thrust into a gatekeeping role.

At the Scaling Bitcoin workshop in Hong Kong, a panel of miners was held with representation from eight of the world's leading Bitcoin mining operations; these miners were said to represent about 90 percent of the computing power of the entire Bitcoin network. Due to the deadlock among developers, this panel—a chance for non-developers to tip the outcome of the debates—became the high point of the conference; the panel moderator, who was part of a Chinese Bitcoin company, asked the eight panelists, 'I just want to know, like, give everybody a quick chance just to have a quick vote of saying, do we need to increase the block size, yes or no?'

The panelists took turns to express their opinions, generally with respect to the most popular Bitcoin Improvement Protocols (BIP). In the Bitcoin open source community, a *Bitcoin Improvement Proposal* is a written document detailing technical information with respect to proposed changes to Bitcoin. Andresen and other prominent developers published a series of BIPs (numbered from 100 to 105) arguing for various ways of scaling Bitcoin network capacity while awaiting technical solutions like Lightning Network to mature.

But some Chinese miners were apprehensive about taking on the role of gatekeepers. Jinle, a developer at a Bitcoin miner manufacturer, said,

> 'I need to raise one point, that for many years, both miners and mining farms had borne much hardships to support the Bitcoin network. The competition is cutthroat, and we worked hard every single day [maintaining the mining machinery], to support Bitcoin's development. But all of a sudden, you wanted us to change our role [from Bitcoin maintainers] to that liken[ed] to a jury. So, BIP100 is like a case. So

> right now I think there's no lawyer on both sides, so we need a lawyer, means that we need a… I think that's the miners' position right now. They really don't know what [will] happen. We need more information. Yeah.'

These miners expressed the concern about being asked, despite not being technical experts, to vote for different technical propositions—a role they had not expected to perform. But they also raised the point that they might be willing to use fluctuations in Bitcoin's price as indicators of whom they should eventually support. For example, Alan, the CTO of a Bitcoin miner and equipment manufacturer, said,

> 'I would have rather talk[ed] about something else, than to answer this question. Because I believe that this is a developer's problem. The solutions presented were A, B, C, and D, and each of them has its own deficiencies—that is why we should not be hasty—or it may cause much fluctuation in bitcoin's price. What do we miners really care about? In China, miners care most about bitcoin's investment value—we love this. Therefore, scaling should be done incrementally, and I like some of these proposals.'

Without fully understanding the technical soundness of these BIPs, miners like Alan might pay attention to Bitcoin's exchange market to make technical decisions.

At the end of the Scaling Bitcoin workshop, the negotiation remained a deadlock. And at the start of writing of this paper, some of the BIPs' developers, including Andresen, were supporting a new Bitcoin fork, known as *Bitcoin Classic*, as an alternative to Bitcoin Core (the current version of Bitcoin). Right after the workshop, Bitcoin Classic was being supported by all major Bitcoin exchanges such as *Coinbase* and *Bitstamp*—thus representing actors who are more business-friendly—who may have greater concerns about Bitcoin's commercial applications.

5. Negotiating Use Cases and Business Models: Wrestling with External Actors and Infrastructures

In the commercial environment, many Bitcoin startups and ventures were imagining new blockchain-supported business transactions. These business transactions, which will be discussed in this section, include: a blockchain-based equity trading platform, an online game assets market, cryptocurrency wallets, and a pre-IPO stock exchange. The imaginaries driving these developments were differentiated from that of libertarians in a distinctive way, as they did not shy away from institutional participation and also placed less emphasis on providing full user anonymity. But the entrepreneurs still had to contend with other limitations imposed by non-stakeholders—imaginary users and financial regulators.

5.1. Re-imagining Technical Design from User Experience

The main preoccupation of corporate developers was to align the technical design of Bitcoin (what the developers think the transactions would be like), and imagined user experience (how imagined users would use Bitcoin). For example, Bitcoin was being explored as a platform to support real-money trade in online games and virtual worlds. But according to Matt, a developer at a gaming company, cryptocurrencies used in virtual worlds have to be spendable the moment a player receives the money. Yet due to the technical specifications of mining, bitcoins have an average wait time of 10 minutes before a user can transfer them to someone else; these gamers would not want to wait that long.

In another example, digital wallet developers were contesting which technical features of Bitcoin are of value to users. A key technical proposition of Bitcoin is to allow users to hold their own cryptographic keys. These keys can be used to cryptographically prove that they are the owner of certain bitcoins and allow these users to fully control their money. But not all wallet developers think that users are the right actors to hold on to their own private keys—for loss of such keys would mean a permanent loss of their cryptocurrency. For example, Jean, an artist who developed a cryptocurrency for the art world, commented that she prioritizes ease of use over privacy,

> '[Let] someone else [hold my keys]. I'm very "irresponsible," and I lose everything. That being said, everybody's talking about wallets [and their privacy and security features]. Well, the way that I look at a wallet … is I use it more as a communication portal and sort of a place to hang out, which is, I think, a little bit different from what the other guys are doing.'

At the conference, many of the discussions were centered on clarifying imaginaries of developers, such as Jean, who challenged the other developers' visions.

In reality, few users were present at the conference to validate these imaginaries; rather, a group of investors (e.g., incubators) were overseeing the technologies' potential to deliver sufficient user experience. For example, during the Inside Bitcoin conference, we conducted an informal interview with an investor, Kyle, whose angel investor group was entering the Bitcoin industry. Kyle likened blockchains to the early days of the Internet when there was no GUI and it was not user-friendly. In those days, working out technical concerns was more important than building a user-friendly system. But Kyle argued that actors in the Bitcoin industry now need to be more focused on developing actual use cases,

> 'Now what I'm seeing is that [people are focusing] more [on] technical aspects, people are discussing the technology, but still… the real application needs to come out so everybody can use it… once we get to that stage, then we can claim it's successful. But if there's no real application now, or few applications now, it's hard to get mass adoption. So, we need more entrepreneurs to make this work.'

For the Bitcoin companies, investors like Kyle acted as a different kind of gatekeeper by only funding entrepreneurs who could design technologies that deliver good user experience.

Since the invention of Bitcoin, many other developers have also created other independent blockchains to serve a variety of purposes. One such blockchain, the Ethereum network, was developed as a new blockchain that supports features unavailable in Bitcoin; that is, generalized software programming around digital assets (i.e., smart contracts) that runs autonomously in its peer-to-peer network (e.g., developing a peer-to-peer derivative trading platform that automates the work of traditional counterparties). In order to resolve the 10 minutes block time issue in online games, entrepreneurs such as Matt re-imagined their designs by utilizing the Ethereum blockchain, instead of Bitcoin's blockchain,

> 'And there's also another thing with gaming in particular, not just the storage of assets, but in a real gaming environment you have to [support] dynamic network consensus…. you have to have this virtual environment updated with all the players in real time. How are you going to get that into a blockchain with ten-minute block times… And in Bitcoin, it's going to be a hundred years before you get the Bitcoin developers to agree to such a thing [referring to the Scaling Bitcoin impasse]. Whereas a coin right now that's starting out, that's only eight months old or six months old, these sort of protocol changes can just be put on top of it experimentally.'

Matt envisioned that to ensure the best user experience, companies need to deliberate on the flexibility afforded by alternative blockchains if they provide better user experiences.

Each of these entrepreneurs revised their imaginaries to match who they thought their users will be, and what transactions these users will perform. And the incubators as gatekeepers helped ensure that these entrepreneurs were developing parts of an infrastructure that may support financially sustainable use cases.

5.2. No Choice but to Comply: Re-imagining Bitcoin in the Peculiar World of Financial Regulation

In the US, Bitcoin is such a versatile medium of trade that, depending on its uses by companies, stakeholders may need to fulfill a wide range of regulatory requirements. The CFTC (Commodity Futures Trading Commission) has treated Bitcoin as a commodity; the IRS has viewed it as property; and FinCEN has seen it as currency; each regulating Bitcoin as such. For example, as a currency, Bitcoin businesses that mediate transfer of bitcoins from one user to another may need to acquire a Money Service Business (MSB) license; and the licensing process is tedious as it also varies from state to state.

At Inside Bitcoins, Vincent, a US attorney with experience in Bitcoin cases, discussed how law enforcement agencies would err on the safe side if entrepreneurs did not cooperatively help them understand Bitcoin businesses. For example, a FinTech (financial technology) business known as *Sand Hill Exchange* developed a stock exchange platform involving the use of Bitcoin that allowed startup companies to obtain public funding outside of traditional stock exchanges. Ian, another attorney with experience in Bitcoin, described how Sand Hill Exchange eventually had to stop operating and pay a $20,000 settlement fee,

> 'It doesn't matter [whether] you think, "Oh, I'm just small" or, "It's still too early. They'll never know that I'm here." Because these entrepreneurs have done what they've seen other entrepreneurs do, right? Which is, "I've got an app. I'm going to do a press release"…. And within two days of a *Financial Times* blogger blogging about this pre-IPO program that had just been released, they got cease and desist letters from the SEC.'

Several legal professionals at an Inside Bitcoin panel said that stakeholders have to be aware that banks were wary of Bitcoin businesses because of their exposure to regulatory issues, and these banks need to weigh the likelihood and cost of being implicated in potential lawsuits. Thus, Ian suggested a workaround:

> 'When I was a general counselor at CoinBuy [pseudonym], one of our issues, one of our stratagems was that we had to keep three or four bank accounts open at any point in time, because one bank account may just close for no reason.'

We interviewed an incubator, David, with significant experience working with entrepreneurs, who explained this complex landscape from the corporate developers' perspective,

> 'For example, I talked to a founder of BitTech [pseudonym]…. She told me she contacted about 140 banks for one exchange, because in the US you need one license per state. She contacted 140 banks. Out of these 140 banks, she may be able to work with five. She has a great profile. The development team comes from Wall Street firms…. The banks not only are not helping, they are actually preventing you from opening your business because if out of 140 banks, 135 say no, then imagine the tens of hundreds

> of entrepreneurs who just try 10 banks, and then 10 banks said no, or 20 banks, and then 20 banks say no. What do they do? They don't do it. Right?'

As David described, many entrepreneurs in the Bitcoin space often encountered stringent regulatory requirements that surprised them—they introduce a significant hidden cost to starting up a Bitcoin business.

According to Max, significant investment and compliance preparation needs to be undertaken by companies venturing into the industry,

> 'Time frame can be, depending on the space that you're operating, it could be anywhere between six to 18 months. Overall costs, depending on how it's done, could be anywhere from a couple hundred thousand to under 2 million dollars. ... That's actually a tremendous [capital] burn-rate for a lot of people… So, a lot of times, we find people go too fast. This is kind of the path where you essentially have to put your best foot forward [compliance-wise], strategically. If you put your best product forward with your best foot forward, there's high likelihood of success.'

Bitcoin technologies, when developed as financial products, could face stringent regulations, thus halting thinly funded entrepreneurial ideas in their tracks. In some cases, demands of financial compliance may be only resolvable through increased capitalization to fund compliance efforts. To an extent this resolution is a double-edged sword—it allows blockchains to be integrated into the financial industry, but at the same time severely limits the way lowly capitalized entrepreneurs can crystallize their imaginaries.

In these final sections, we will first discuss the processes of imaginaries and crystallization in Bitcoin, followed by discussion of diversification and limits to infrastructuring mediated by both internal and external factors.

6. Concrete Imaginaries and Crystallization through the Power of Gatekeepers

Bitcoin stakeholders clarified what they meant by 'trustless' and other abstract visions by sharing detailed imaginaries in papers, presentations, and discourse formats. This sharing clarified each stakeholder's position, and helped negotiate and construct Bitcoin's design and use cases. It is thus important to examine imaginaries as embodying different levels of specificity.

In their paper, Neumann and Star (1996) discussed the importance of *abstract imaginaries* in infrastructuring,

> 'Imaginaries and metaphors are used to translate between object world views. The attempt to bring so many dispersed and varying views and foci together in one unified project necessitates a lack of specificity which is achieved through the shared imaginary or all the diverse views and groups cannot be accommodated.' (p. 236)

When remaining as an abstract call-to-action, imaginaries drive participation among those who are compelled by the vision. But such abstract visions are also termed by Gregory (2000) as 'incomplete utopian projects.' Incomplete utopian projects are characterized by persistence but also their futility. 'Utopian projects outlive any particular attempt at realization, nor is any particular failure sufficient to spell the end of a utopian quest' (Gregory 2000, p. 198), but also 'simultaneously characterized by their unrealizability and their devotees' tendencies to over-reach reality in their pursuit' (p. 194). Therefore, when left in an abstract form, the Bitcoin utopia without human intermediaries can be seen as an 'incomplete utopian project.'

In order for negotiation to converge towards crystallization points, stakeholders need to increase the specificity of their imaginaries (e.g., Bitcoin developers present BIPs to specify their imagined designs of the blockchain) (Neumann and Star 1996). *Concrete imaginaries* are detailed descriptions, for the purpose of negotiations, of how stakeholders believe their imaginaries would be crystallized; and these imaginaries are expressed as texts, narratives, diagrams, or prototypes. From an activity theory perspective, these writings, signs, and tools provide semiotic mediation (i.e., mediation through descriptions and demonstrations) which foster deeper interactions among stakeholders (Vygotsky 1962). But concrete imaginaries (e.g., Bitcoin BIPs) also reveal contradictions among stakeholders, thus requiring them to revalidate their own designs, and attempt to resolve conflicts. For example, even though all Bitcoin developers agreed on the abstract notion of 'trustless,' as soon as they tried to specify what 'trustless' truly means, they found themselves disagreeing on development timelines, transaction fees, transaction time, user roles and tasks, and whether a compelling use case infringes on existing regulations. Thus, while abstract imaginaries bring people together, concrete imaginaries breed tensions, and need resolution in order to crystallize the system designs.

The term 'boundary object,' from Star and Griesemer (1989), refers to an object that serves informational needs of several communities of practice; that can be used as a 'common object' between these communities, while at the same time it is flexible enough to be 'tailored to local use'; and that can be as abstract as an idea or as concrete as an artifact. What stakeholders want to crystallize through negotiation are the design features of boundary objects (e.g., the Bitcoin blockchain). According to Neumann and Star (1996), crystallization happens when a stakeholder 'realizes what performances are no longer possible.' In the case of Bitcoin, we uncovered a political process in which gatekeepers may influence crystallization by determining designs of boundary objects but at the expense of some of the other stakeholders (i.e., without the need for everyone to agree). In general, gatekeepers inherit this power from artifacts and practices of the installed base; for example, committers in open source communities have power over other developers (via design of the open source websites), and incubators in startup communities have power over entrepreneurs (via startup funding processes). Depending on the specific gatekeeping rules (e.g., bitcoin price or user experience), tensions arise between stakeholders supporting these rules and those who think differently.

In the paper, 'Do Artifacts Have Politics,' Winner (1980) discusses how certain artifacts can confer a disproportionate amount of power to some social groups at the expense of the others. Therefore, in a system with such artifacts, certain stakeholders could become incidental gatekeepers not because they were appointed by people, but due to the system design. For example, during the Scaling Bitcoin debates, the bitcoin miners gained unprecedented (and unexpected) power in making decisions regarding designs of the Bitcoin blockchain. This power was obtained from miners having control over critical parts of the emerging infrastructure—the servers running the peer-to-peer network. And the miners chose stability of bitcoin price as one of their gatekeeping rules.

But gatekeeping biases, and tensions which follow, may not completely impede progress; Foot and Groleau (2011) argue that one could view tensions within sociotechnical systems as 'growth buds.' And stakeholders could adapt to the rules imposed by gatekeepers to identify new development directions.

7. Imaginaries Branching and Internalization of Features of External Infrastructures

In a large-scale infrastructuring project, irreconcilable differences among stakeholders may be inevitable. Through the concept of *imaginaries branching*, we describe the process in which stakeholders who could not crystallize their imaginaries sought to bring their design along alternative pathways, thus diversifying Bitcoin's main trunk into dozens of branches and reaching out to other potential user bases.

Imaginaries branching happens when a set of imaginaries migrates to a new context in order to identify new development opportunities. From our data, this group of stakeholders attempted to create alternate boundary objects to support their work (e.g., by creating Bitcoin Classic). By branching out of the original context, they avoided entanglement with incompatible gatekeeping rules. Thus, even though gatekeepers have great power, they cannot ignore too many stakeholders' visions, as it may lead to excessive branching, thus diluting the infrastructuring effort.

Imaginaries branching may also occur when new opportunities emerge in other contexts, such as when startup funding was available to support Bitcoin and blockchain businesses. For example, this form of branching led to the Bitcoin developers imagining their infrastructuring work in the online gaming and financial industries. We argue that this separation of imaginaries into branches is necessary due to misalignment of purposes, practices, assumptions, biases, and constraints of different stakeholders and gatekeepers (e.g., investors of corporate environments expect startups to conform to regulations, over and above having anonymous features).

Thus, when imaginaries branching occurs, when imaginaries enter a new context in order to seek out new opportunities or to take advantage of existing opportunities, stakeholders are still going through the phases of crystallization: identifying the limitations of their imaginaries and revising them to fit the new context. However, these stakeholders have chosen to crystallize their imaginaries in systems that may have different gatekeepers.

Note that imaginaries branching does not necessarily cause an infrastructure to split into different infrastructures. An infrastructure is a complex and massive assemblage, and some boundary objects remain shared between contexts. For example, Bitcoin Classic was developed out of Bitcoin Core source code. Similarly, both open source developers and entrepreneurs shared the many blockchains as boundary objects in the Bitcoin infrastructure. Thus, imaginaries branching can lead to complementary development of linked parts of the *same* infrastructure (e.g., one offering greater anonymity, while the other offers better user experience)—attracting a greater diversity of users. Indeed, Lustig and Nardi (2015) argue, 'The diversity of alternate [blockchains] provides the heterogeneity needed to continue with the utopian visions of Bitcoin users if Bitcoin fails to live up to their expectations' (p. 751). This diversification of the blockchain also benefits those businesses favoring flexible selection of blockchains which serve their needs.

Imaginaries branching will not continue to expand unabated. At some point, it will branch into contexts already containing external infrastructures. These infrastructures may contain gatekeepers who have strong sociopolitical leverage to impose specific standards, social practices, and regulations on the Bitcoin imaginaries.

Infrastructuring work will inevitably attempt to disrupt existing technologies, change user practices, or transform organizational formations. But each context is already the shared 'territory' of existing infrastructures; that is, every user which the infrastructuring work attempts to serve is likely already habituated to, or regulated and structured by, existing technologies, user practices, or institutions. For example, within a house, there is the electrical grid, fiber optics cable, and gas and water supply, not including other rules governing their uses such as utility bills, property tax, and mortgages. And within the startup community, there exists an installed base of incubators and venture capitalists with predefined roles to guide the Bitcoin companies (see Lindtner, Hertz, and Dourish, 2014); but they also share the context with financial industry actors and their regulations, which even incubators like David did not fully understand. While the infrastructuring work attempts to disrupt these artifacts and practices, powerful actors may resist these changes by enforcing their own standards and practices on the infrastructuring work (see Jabbar and Bjorn 2017). Thus, while Neumann and Star (1996) likened infrastructuring to a game of Tetris in which new pieces build on an older foundation, this metaphor simplifies the complexity of the competitive relationship among infrastructures for standards, regulation, users, and markets. Importantly, the aim of an infrastructuring project like that of Bitcoin is not simply to build a system for user benefits, but also to disrupt and displace existing financial systems (Maurer et al. 2013; May 2001); and these old infrastructures will push back against the infrastructuring work.

In our case, our stakeholders were attempting to revise their imaginaries based on financial regulations. Note that financial regulations in the US are complex boundary objects created out of sociopolitical deliberations, in response to public sentiments, and negotiated by the Congress, the US president, and interest groups (Martinez-Moyano et al. 2014). These external forces create constraints to rein in excessive risk-taking in the financial industry, but may also unintentionally limit innovations (Martinez-Moyano et al. 2014). As was discussed by Martinez-Moyano et al. (2014), 'At the heart of [fluctuating financial regulatory demands] is the tension between production goals that focus on short-term, certain, and salient benefits with required adherence to production-constraining rules that attempt to mitigate long-term, uncertain, and nonsalient risks' (p. 322). Thus, in Bitcoin's infrastructuring, regulatory compliance represents a tradeoff strategy (with user experience) to access large consumer markets (e.g., wallets, online gaming, crowdfunding, and other digital assets exchange cases).

With respect to the ways old and new infrastructures interact, Zhang (2017) uses the term 'internalize,' from economic anthropology, to describe the need for an emerging infrastructure to adopt features of the older infrastructure it aims to disrupt or replace. We may likewise describe the role of powerful gatekeepers as that of ensuring that emerging infrastructures (e.g., blockchains) *internalize* and adhere to important standards and regulatory mechanics instead of developing all on its own. In fact, this process of internalizing features of external infrastructures may allow the new infrastructure to inherit sociopolitical functions of the old infrastructure (e.g., the SEC license helps safeguard interest of investors). In addition, by inheriting these established features, stakeholders may be able to establish a deeper level of trust with users and external institutions (see also Sas and Khairuddin 2015). Thus, part of the 'inertia' of installed bases may be described as mutual exchanges between new and old infrastructures, each to internalize boundary objects of the other.

In the face of such a complex process of imagining, negotiating, and learning design limitations, stakeholders may take a while before they find a design that fits in at least one context of an infrastructuring space. To mitigate this process, system developers may want to ensure that all groups of stakeholders are rightfully represented during negotiation. And a way to do so is for the stakeholders to agree on a social process of making design decisions (e.g., voting through elected representatives), rather than to allow a few stakeholders to dictate the negotiation process. Also, stakeholders should engage with external gatekeepers (e.g., legal counsels) proactively and as early as possible. For example, in many cases we examined, developers were taken by surprise by user experience demands or complexity of financial regulations. In these cases, early engagement with external gatekeepers to understand their perspectives may help each stakeholder develop more realistic imaginaries.

The interaction between an emerging infrastructure and other powerful infrastructures leads to a more difficult question: what constitutes a level playing field between infrastructures? From our data, Bitcoin imaginaries were internalizing financial regulations. And in order to fulfill these regulations, Bitcoin companies needed to increase their capitalization and prematurely consolidate small businesses. If we look beyond Bitcoin infrastructuring, recent development of computing platforms has many examples of promising technologies being withheld by old rules. For example, intellectual property laws halted academic publication of encryption research and Napster's file sharing services (Yochai Benkler 2006), and prevented online game modders from owning the very software they had developed (Burk 2010; Kow and Nardi 2010). On the other hand, historically, new infrastructures, such as the waves of industrialization and globalization, have also been forcefully imposed on politically weak populations and traditions (Shackel 1996; Verran 1998; Zhang 2017). Thus, when infrastructures collide, the process of internalizing each other's boundary objects contains more complex social and political implications. Therefore, the roles of gatekeepers and the ways they mediate imaginaries and crystallization, and the outcomes these practices entail, have to be further examined in future studies.

8. Conclusion

In this paper, we described imaginaries and crystallization as important concepts of infrastructuring. Abstract forms of imaginaries provide the collective visions, motivations, and common ground for collaborative work among stakeholders. And concrete forms of imaginaries also mediate negotiation among stakeholders so as to clarify limitations to designs of boundary objects. However, in large-scale infrastructuring projects like that of Bitcoin, negotiation alone may not be sufficient for arriving at design decisions. In this case, gatekeepers at key parts of the infrastructure could impose rules to influence which imaginaries will crystallize into boundary objects. And stakeholders may adapt to these rules by revising their imaginaries, or to seek new opportunities through imaginaries branching—the diversification of imaginaries to new contexts which may better support their crystallization. From our data, we saw how imaginaries branching contributes to Bitcoin's diversifying infrastructure. But in these new contexts, an infrastructuring work may find new limits to its expansion, for a context is not an empty vessel but already contains powerful external infrastructures. And these external infrastructures (e.g., the financial industry) can impose their own standards on the infrastructuring project. While these standards limit the imagined potentials of Bitcoin, their internalization helps connect the infrastructuring work with external infrastructures.

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References

Andriopoulos, Constantine; and Marianne W. Lewis (2008). Exploitation-Exploration Tensions and Organizational Ambidexterity: Managing Paradoxes of Innovation. *Organization Science*, vol. 20, no. 4, pp. 696–717.

Austin, Robert D.; Lee Devin; and Erin E. Sullivan (2011). Accidental Innovation: Supporting Valuable Unpredictability in the Creative Process. *Organization Science*, vol. 23, no. 5, pp. 1505–1522.

Benkler, Yochai (2006). *The Wealth of Networks: How Social Production Transforms Markets and Freedom*. New Haven, CT: Yale University Press.

Bowker, Geoffrey C.; and Susan Leigh Star (1998). Building Information Infrastructures for Social Worlds: The Role of Classifications and Standards. In Toru Ishida (ed.): *Community Computing and Support Systems: Social Interaction in Networked Communities*. Berlin, Germany: Springer, pp. 231–248.

Bowker, Geoffrey C.; and Susan Leigh Star (2000). *Sorting Things Out: Classification and Its Consequences*. Cambridge, MA, USA: MIT Press.

Burk, Dan L (2010). Authorization and Governance in Virtual Worlds. *First Monday*, vol. 15, no. 5. http://journals.uic.edu/ojs/index.php/fm/article/view/2967. Accessed 13 October 2017.

Coleman, E. Gabriella; and Alex Golub (2008). Hacker Practice Moral Genres and the Cultural Articulation of Liberalism. *Anthropological Theory*, vol. 8, no. 3, pp. 255–277.

Constantinides, Panos; and Michael Barrett (2014). Information Infrastructure Development and Governance as Collective Action. *Information Systems Research*, vol. 26, no. 1, pp. 40–56.

Evans, David S.; and Richard Schmalensee (2004). *Paying with Plastic: The Digital Revolution in Buying and Borrowing*. Cambridge, MA: The MIT Press.

Foot, Kirsten; and Carole Groleau (2011). Contradictions, Transitions, and Materiality in Organizing Processes: An Activity Theory Perspective. *First Monday*, vol. 16, no. 6. http://journals.uic.edu/ojs/index.php/fm/article/view/3479/2983. Accessed 13 October 2017.

Gregory, Judith (2000). *Sorcerer's Apprentice: Creating the Electronic Health Record, Re-Inventing Medical Records and Patient Care.* PhD dissertation. University of California, San Diego: Department of Communication.

Hackett, Robert (2017). Ethereum: JPMorgan, Microsoft, Banks Form Blockchain Alliance. Fortune, 28 February 2017. http://fortune.com/2017/02/28/ethereum-jpmorgan-microsoft-alliance/. Accessed 28 September 2017.

Higgins, Stan (2015). Factom Partners With Honduras Government on Blockchain Tech Trial. CoinDesk, 15 May 2015. https://www.coindesk.com/factom-land-registry-deal-honduran-government/. Accessed 1 October 2017.

Hyperledger (2017). Members – Hyperledger. https://www.hyperledger.org/members. Accessed 28 September 2017.

Jabbar, Karim; and Pernille Bjorn (2017). Growing the Blockchain Information Infrastructure. In *CHI '17. Proceedings of Conference on Human Factors in Computing Systems*, *Denver, CO, USA, 6 - 11 May 2017*. New York, NY, USA: ACM Press, pp. 6487–6498.

Jasanoff, Sheila; and Sang-Hyun Kim (2015). *Dreamscapes of Modernity: Sociotechnical Imaginaries and the Fabrication of Power*. Chicago, IL, USA: University of Chicago Press.

Karasti, Helena; Karen S. Baker; and Florence Millerand (2010). Infrastructure Time: Long-Term Matters in Collaborative Development. *Computer Supported Cooperative Work*, vol. 19, no. 3–4, pp. 377–415.

Khairuddin, Irni Eliana; Corina Sas; Sarah Clinch; and Nigel Davies (2016). Exploring Motivations for Bitcoin Technology Usage. In *CHI EA '16. Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems, San Jose, CA, USA, 7 - 12 May 2016.* New York, NY, USA: ACM Press, pp. 2872–2878.

Khalid, Arsalan (2017). Deciding Between Ethereum or Hyperledger: Contributing Towards Open Source Development. Medium, 12 March 2017. https://medium.com/@arsalanskhalid/deciding-between-ethereum-or-hyperledger-contributing-towards-open-source-development-4cb16e9f5290. Accessed 28 September 2017.

Kow, Yong Ming (2017). Cryptocurrencies and Their Potential for Large-Crowd, Cost-Effective Transactions in Peer Production. *First Monday*, vol. 22, no. 8. http://journals.uic.edu/ojs/index.php/fm/article/view/6617/6512. Accessed 13 October 2017.

Kow, Yong Ming; and Xianghua Ding (2016).“Hey, I Know What This Is!”: Cultural Affinities and Early-Stage Appropriation of the Emerging Bitcoin Technology. In *GROUP '16*. *Proceedings of the ACM International Conference on Supporting Group Work, Sanibel Island, FL, USA, 13 - 16 Novemenber 2016.* New York, NY, USA: ACM Press, pp. 213-221.

Kow, Yong Ming; and Bonnie Nardi (2010). Who Owns the Mods? *First Monday*, vol. 15, no. 5. http://journals.uic.edu/ojs/index.php/fm/article/view/2971/2529. Accessed 13 October 2017.

Lindtner, Silvia; Garnet D. Hertz; and Paul Dourish (2014). Emerging Sites of HCI Innovation. In *CHI '14. Proceedings of the 32nd Annual ACM Conference on Human Factors in Computing Systems, Toronto, ON, Canada, 26 April - 1 May 2014.* New York, NY, USA: ACM Press, pp. 439–448.

Lustig, Caitlin; and Bonnie Nardi (2015). Algorithmic Authority: The Case of Bitcoin. In *HICSS '15. Proceedings of the Annual Hawaii International Conference on System Sciences, Kauai, HI, USA, 5 January - 8 January 2015. Washington, D.C., USA: IEEE*, pp. 743–752.

Martinez-Moyano, Ignacio J.; David P. McCaffrey; and Rogelio Oliva (2014). Drift and Adjustment in Organizational Rule Compliance: Explaining the “Regulatory Pendulum” in Financial Markets. *Organization Science*, vol. 25, no. 2, pp. 321–328.

Maurer, Bill; Taylor C. Nelms; and Lana Swartz (2013). “When Perhaps the Real Problem Is Money Itself!”: The Practical Materiality of Bitcoin. *Social Semiotics*, vol. 23, no. 2, pp. 261–277.

Maxwell, Deborah; Chris Speed; and Dug Campbell (2015). 'Effing' the Ineffable: Opening up Understandings of the Blockchain. In *Proceedings of the 2015 48th British HCI Conference, Lincoln, UK, 13 - 15 July 2015*. New York, NY, USA: ACM Press, pp. 208–209.

May, Timothy C (2001). Crypto Anarchy and Virtual Communities. In Peter Ludlow (ed.), *Crypto Anarchy, Cyberstates, and Pirate Utopias*. Cambridge, MA, USA: MIT Press, pp. 65–79.

Murphy, Keith M (2004). Imagination as Joint Activity: The Case of Architectural Interaction. *Mind, Culture, and Activity*, vol. 11, no. 4, pp. 267–278.

Nakamoto, Satoshi (2008). Bitcoin: A Peer-to-Peer Electronic Cash System. https://bitcoin.org/bitcoin.pdf. Accessed 1 October 2017.

Neumann, Laura J.; and Susan Leigh Star (1996). Making Infrastructure: The Dream of a Common Language. In Jeanette Blomberg, Finn Kensing, and Elizabeth Dykstra-Erickson (eds.): *PDC '96. Proceedings of the Participatory Design Conference*, *Cambridge, MA, USA, 13 - 16 November 1996*. Palo Alto, CA, USA: Computer Professionals for Social Responsibility, pp. 231–240.

Pipek, Volkmar; and Volker Wulf (2009). Infrastructuring: Toward an Integrated Perspective on the Design and Use of Information Technology. *Journal of the Association for Information Systems*, vol. 10, no. 5, pp. 447–473.

Poon, Joseph; and Thaddeus Dryja (2016). The Bitcoin Lightning Network: Scalable Off-Chain Instant Payments. Draft Version 0.5.9.2. https://lightning.network/lightning-network-paper.pdf. Accessed 13 October 2017.

Reijers, Wessel; and Mark Coeckelbergh (2016). The Blockchain as a Narrative Technology: Investigating the Social Ontology and Normative Configurations of Cryptocurrencies. *Philosophy & Technology*, October 2016. https://doi.org/10.1007/s13347-016-0239-x. Accessed 13 October 2017.

Resnick, Paul; Joseph Konstan; Yan Chen; and Robert E. Kraut (2011). Starting New Online Communities. In Robert E. Kraut and Paul Resnick (eds.): *Evidence based Social Design: Mining the Social Sciences to Build Online Communities*. Cambridge, MA, USA: MIT Press, pp. 231-281.

Ribes, David; and Thomas A. Finholt (2007). Tensions Across the Scales: Planning Infrastructure for the Long-Term. In *GROUP '07. Proceedings of the 2007 International Conference on Supporting Group Work, Sanibel Island, FL, USA, 4 - 7 November 2007.* New York, NY, USA: ACM, pp. 229–238.

Sas, Corina; and Irni Eliana Khairuddin (2015). Exploring Trust in Bitcoin Technology: A Framework for HCI Research. In Bernd Ploderer, Marcus Carter, Martin Gibbs, Wally Smith, and Frank Vetere (eds): *OzCHI '15. Proceedings of the Annual Meeting of the Australian Special Interest Group for Computer Human Interaction, Parkville, VIC, Australia, 7 - 10 December 2015.* New York, NY, USA: ACM Press. pp. 338–342.

Shackel, Paul A. (1996). *Culture Change and the New Technology: An Archaeology of the Early American Industrial Era*. New York, NY, USA: Plenum Press.

Simonite, Tom (2015). The Looming Problem that Could Kill Bitcoin. MIT Technology Review, 28 August 2015. https://www.technologyreview.com/s/540921/the-looming-problem-that-could-kill-bitcoin/. Accessed 1 October 2017.

Star, Susan Leigh; and James R. Griesemer (1989). Institutional Ecology, 'Translations' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907–39. *Social Studies of Science*, vol. 19, no. 3, pp. 387–420.

Star, Susan Leigh; and Karen Ruhleder (1996). Steps Toward an Ecology of Infrastructure: Design and Access for Large Information Spaces. *Information Systems Research*, vol. 7, no. 1, pp. 111–134.

Verran, Helen (1998). Re-Imagining Land Ownership in Australia. *Postcolonial Studies*, vol. 1, no. 2, pp. 237–254.

Vygotsky, Lev S. (1962). *Thought and Language*. Cambridge, MA: MIT Press.

Wikipedia (2017). Chatham House Rule. https://en.wikipedia.org/wiki/Chatham_House_Rule. Accessed 1 October 2017.

Winner, Langdon (1980). Do Artifacts Have Politics? *Daedalus*, vol. 109, no. 1, pp. 121–136.

Wong, Joon Ian (2015). Lloyd's Sees Blockchain's Potential For Insurance Markets. CoinDesk, 27 November 2015. https://www.coindesk.com/lloyds-sees-blockchains-potential-insurance-markets/. Accessed 1 October 2017.

Zhang, Shaozeng (2017). From Externality in Economics to Leakage in Carbon Markets: An Anthropological Approach to Market Making. *Economic Anthropology*, vol. 4, no. 1, pp. 132–143.