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Function, Form, Materiality and the Enigma of Digitality

Is Bitcoin Remaking Money as We Know It?

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ABSTRACT

This article suggests that computation and digitality can reconfigure the entanglement between function, form and materiality and in the process change the signification of traditional material forms. To illustrate these claims, bitcoin, a digitally constituted currency dubbed by proponents as 'a new kind of money', is analyzed in its reconfiguration of traditional material forms of money. The case of bitcoin instantiates reconfiguration through a series of digitally mediated steps: (1) Abstraction of finite and material money supply into an infinite process of cryptographically secured record keeping, constrained only by computational capacity (the blockchain) (2) Decentralization and decontextualization of actions and processes of bitcoin creation and dissemination (mining which decenters intermediaries and regulators in supply), and (3) Deconstruction of formal and material sources of signification, legitimation, meaning and control of money (such as material substrates used to signify value and the formal authorities that legitimate such). These insights call for critical reflection of paradigmatic assumptions of sociomateriality in Information Systems research, particularly, in relation to computational and digital artifacts and their implication for materiality, form and function.

Introduction

Are form and materiality required for function? This article argues that computation and digitality reconfigure the entanglement between function, form and materiality and in the process change the signification of traditional material forms. Digital currency, specifically, the cryptocurrency, bitcoin—whose function as medium of exchange or money is only marginally material but relies chiefly on bits, bytes and complex computation and has been dubbed by proponents as a "new kind of money"*—is used as an illustrative case study to support this claim. The relationship between function, form and materiality of money—an entity with social, functional, formal and material significance—is studied to yield a richer understanding of the bitcoin case itself and to further interrogate sociomateriality assumptions in light of emerging work on digital artifacts and systems. The article proceeds with theoretical discussions of sociomateriality, digitality and money, followed by presentation of the bitcoin case and an analysis in light of the theoretical discussion.

*Bitcoin.org, 2014

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Theoretical Framing

Technology, Form, Function and Materiality

Function may be conceived as the purpose fulfilled by an object whereas form is what "provides the mold to which matter enters [...] the *causa formalis* (the receptacle, design, eidos) of a particular object or artifact, distinguished and to some degree juxtaposed to the *causa materialis* (matter, hyle)" (Kallinikos, 2012, pp. 71–72). Materiality is simply taken to mean the "material or physical constitution (or lack of) of technological object and the implications (social and technical) such a constitution has for design, making and use" (ibid, p.69). Functions are often embodied by their material constitution and hence function and matter may closely relate and be related to the range of social practices related to their use. Technology and technological objects can therefore be said to embody function and form in addition to materiality (Ibid).

In theorizing technology, Information Systems research has typically focused on the materiality of technology, and its use in specific contexts (Kallinikos, 2011; Leonardi, 2011; Markus & Silver, 2008; Zammuto, Griffith, Majchrzak, Dougherty, & Faraj, 2007). This understanding invariably enlists materiality in the understanding of function, and subsequently delimits understanding of technology to immediate, contextual settings and practices where materiality is discernible. Sociomateriality, a major perspective in Information Systems research, is pertinent to this tradition (see for discussion, Leonardi, Nardi, & Kallinikos, 2012; Leonardi, 2013). Sociomateriality—the idea that "the social and the material are to be considered inextricably related [and that] there is no social that is not also material, and no material that is not also social" (Orlikowski, 2007, p. 1437)—has tended to view technology in its time-space situated context of use where the interaction of humans (the social) and material (technological artifacts) are most observable (Boudreau & Robey, 2005; Malhotra & Majchrzak, 2004; Orlikowski & Baroudi, 1991; Orlikowski & Robey, 1988; Orlikowski, 2007a; Schultze & Orlikowski, 2004).

For not ontologically disentangling materiality from the social and its context, e.g. through the 'practice lens' (Orlikowski, 2007b), sociomateriality is criticized as 'over-socialized' and insufficiently theorizing technology itself (Leonardi, 2013, p. 64). But such critiques of sociomateriality, Leonardi (2013) notes, tend to give technology more of a causal role in our understanding of the social application of technology. Consequently, such a discursion from the perceived socialized view of sociomateriality leads to the treatment of technology *per se* as a structure, not unlike certain kinds of institutional structures (Kallinikos, Hasselbladh, & Marton, 2013; Kallinikos, 2009a, 2009b), and inevitably leads to accusations of technological determinism (Kallinikos, 2002; Smith, 1994; Winner, 1993).

Yet, even if one rejects technological determinism in its weak or strong forms, the sociomateriality approach in Information Systems faces a challenge to reconcile contemporary technological developments that punctuate the comfortable balance between abstract, non-localized technological operations and the materiality of 'real things' (Feenberg, 2005; Kallinikos, 2012). This study proposes that with increasing sophistication of computation and digitalization, progressive reconfiguration of the assumed coupling between function and materiality of technology requires recognition, if not reconciliation with sociomateriality's assumptions.

Kallinikos (2012) argues that "the bonds tying the invention and making of technological objects and patterns to matter have increasingly become loosened over the course of technological evolution" due largely to the flexible, abstract, and logical nature of computational software that undergirds many technologies (p.83). Hence, "technological operations could ultimately be seen as decontextualized conceptual arrangements (templates or matrices) on the basis of which reality is ordered to objects or patterns." (ibid). From such a perspective, an implication of computational technology is that while materiality is necessary for instrumentality, it is not sufficient. Generally, the relationship between function and materiality is mediated by form (design) –the application of matter to functional ends. Thus, technological artifacts can be seen to combine form and materiality in a continuum of proportions to arrive at various functions. At the two ends of such continuum, a crowbar for example, might admit more matter than form for the performance of its function whereas a piece of digital software requires more form than matter (Kallinikos, 2012, p.71).

This view not only suggests some partial independence of form, function and materiality but also puts function—rather than materiality—at the center of understanding technology and technological processes (see e.g., Kallinikos' (2009) characterization of technology as essentially functional simplification and closure). Function, given such fluid interrelation with form and substrate, is thus not merely material but also requires social and communal understandings against a background of established beliefs, and practices (Pinch, 2008). Function should therefore be studied with this in view and not separately given that the enactment of function can take on a communal understanding beyond situated practice.

Challenging the assumed enduring entanglement of form, function and materiality rather than admitting it as a given (see e.g. Kallinikos, 2012, p. 83; Pinch, 2008), is neither to argue for a diminished importance of materiality nor to suggest a 'non material' view of technology. Rather, the suggestion is that by adopting a focus on function rather than materiality, digital technology may be better theorized in its functional abstractions and processes of instrumentalization rather than their immediate application in a material *milieu* by actors in a situated context, as has typically been the mode in sociomateriality research.

The Challenge of Digitality

The nature of digital artifacts creates an enigma in the way goods and services are produced and consumed virtually. This enigma of function, form and materiality might be understood by first understanding the nature of digital artifacts and related computation. Digital forms because of their lack of stability, endurance, and their general dissimilarity to objects have been described as "non-material" (Faulkner & Runde, 2009, 2011), as having a "dubious ontology" (Allison, Currall, Moss, & Stuart, 2005, p. 364), as "quasi-objects" (Ekbia, 2009) and as having "ambivalent ontology" (Kallinikos, Aaltonen, & Morton, 2013).

Digital systems comprise functions, relations and artifacts that can often be recombined across platforms and infrastructures to create new products and production systems that often push previous boundaries (Langlois, 2002; Merrifield, Calhoun, & Stevens, 2008; Yoo, Henfridsson, & Lyytinen, 2010). They are often characterized by incompleteness which allows 'generativity', constant making and remaking of new functions and forms (Garud, Jain, & Tuertscher, 2008; Zittrain, 2006, 2008), a process that happens through data homogenization (binary code), reprogramming and self-referentiality (Yoo et al., 2010).

Based on such properties, how do digital processes reconfigure function from form and from materiality? Faulkner & Runde (2009,2011) in their study of computer files note how non-material bit strings emancipate digital functions from their material bearers or substrates such as hard drives, CD-ROMs etc. Yoo et al., (2010) also highlight the embededdness of digital code into layered and modular architectures that still allow separation of content from physical devices and infrastructures. Ekbia (2009) further emphasizes the processual and relational significance of digital artifacts that go beyond their implicit materiality.

Kallinikos' (2012) description of 'loosening' between function, form and matter brought on by digital code is further elaborated in Kallinikos et al., (2013) where they suggest an encompassing framework of four digital attributes: editability, interactivity, reprogrammability/ openness and distributedness. These core digital attributes push against the boundaries of material objects, with profound implications for how we understand the relation between form, function and materiality of technology. The authors show that the ontology of digital artifacts challenges the nature of objects, established institutions and practices as their form, meaning and functions are digitalized.

What is money?

Money is not easy to define (see discussions in Smithin 2000), but has been described as an object or verifiable record that is *generally* accepted as payment for goods and services and repayment of debts in a particularly country or socio-economic context (Mishkin, 2007; Smithin, 2000; Tobin, 2008). The commonly held functions of money are as a *medium of exchange, a unit of account, and a store of value*. These conditions: (1) general use (2) store of value (3) unit of account and (4) Medium of exchange are considered necessary conditions for money to exist as such (Mankiw, 2009). Money has evolved from commodity money such as gold, silver, conch shells etc., to representative money (using paper, coinage or some other artifact to represent commodity value), and in contemporary times to fiat money, which is legally backed artifact like paper without underlying commodity or intrinsic value (Mankiw, 2009, pp. 80–81).[†]

The use as money of cigarettes in WW2 and stones on the island of Yap, illustrates two critical aspects of money: (1) Money may be viewed as an abstract social institution constituted by information, shared norms, agreement and common understanding.[‡] (2) Simultaneously, money is an entanglement of form, function and materiality in varying degrees at different times and contexts, all undergirded by information and social signification. Gleick (2010) observes that,

> *[...] Money itself is completing a developmental arc from matter to bits, stored in computer memory and magnetic strips [...] Even when money seemed to be material treasure, heavy in pockets and ships' holds and bank vaults, it always was information. Coins and notes, shekels and cowries were all just short-lived technologies for tokenizing information [...]*

But even if we hold, as Gleick (2010) does, that money "always was information" and that physical material is "just short-lived technologies for tokenizing information" (presumably not much different from bits and bytes as information tokens), one might still ask to what extent the functioning of money can be separate from its materiality; that is, if digital money requires materiality? To be sure, electronic payment transactions and the digitalization of finance, especially in banking and retail sectors, has a long history and is by no means novel (see for discussion, Good, 2000; Gosling, 1999; Vogelsang, 2010). Solomon (1997) notes the staggering amount of virtual money circulating the globe, with just the Federal Reserve's Fedwire and the New York-based CHIPS technology system making up over 2 trillion dollars daily.

To clarify the differences between previous forms and bitcoin, two concepts are useful: monetary space and monetary hierarchy (OECD, 2002). Monetary space refers to the domain wherein a particular form of money serves its function (ibid). For example, the US dollar bill is usable in the United States but could also be used in the international gold market in London. Monetary hierarchy exists within a monetary space and refers to the relation between different forms of money and the degree to which they are generally preferred to each other and are convertible across forms (from the most preferred e.g., sovereign debt such as government issued currency to softer forms like vouchers, coupons, frequent flyer miles, Facebook credits etc.). General preferredness depends primarily on two attributes: liquidity (ease of conversion to a dominant currency) and effectiveness at performing the general functions of money (medium of exchange, unit of account and store of value) (ibid).

By evaluating against these two concepts, it is clear that discussions of electronic or "e-money" are often not concerned with new forms of money *per se* but rather, new ways that existing forms can be used within the same or different monetary domains and hierarchical frames (Figure 1). This is an important distinction to make if one is to appreciate the difference between bitcoin and previous forms, even if one rejects bitcoin's novelty or legitimacy on some other grounds.

† Two special cases help clarify the points raised. The first is the use of cigarettes as a form of commodity money in special situations such as during WWII by Nazi prisoners of war (Radford, 1945). The second case involves money on the small Pacific Island of Yap, called *fei*. Fei was stone wheels up to 12 feet in diameter that could be carried around laboriously for exchanges, and could thus be seen as something between commodity and fiat money. Given the cumbersome physicality of the fei it soon became common practice to exchange the claim to the *fei* rather than the *fei* itself. The limit of this practice was tested when a valuable *fei* stone was lost at sea during a storm. Since the owner lost his money accidentally and not through neglect, people of Yap agreed to honor his claim to the *fei* and it remained valuable for generations even though no one alive had seen his stone (Angell, 1929, pp. 88–89).

‡ See Searle (1995a, 1995b) for extensive discussion of the ontology and implications of social realities such as money

Aglieta also suggests that a threefold rationale of abstraction, centralization, and control can be used as a framework to distinguish between various forms of money (OECD, 2002,pp.31-68). Abstraction refers to the changing definitions of the unit of measurement that are becoming increasingly abstract through the detachment of the unit of money from the unit of weight through collective acceptance of nominal value (e.g. monetary evolution from objects like stone to intrinsically valuable objects like gold, to fiat, to representative tokens like credit cards, to virtual units like bitcoin); centralization refers to the processes by which a central issuer renders general acceptance to the definition of the unit of measurement within a payment system consisting of trading relations among networks or network of networks; control (regulation) refers to the processes by which trust is maintained between debtors and creditors within the monetary system in order to avoid a breakdown of the relational flow of economic value.

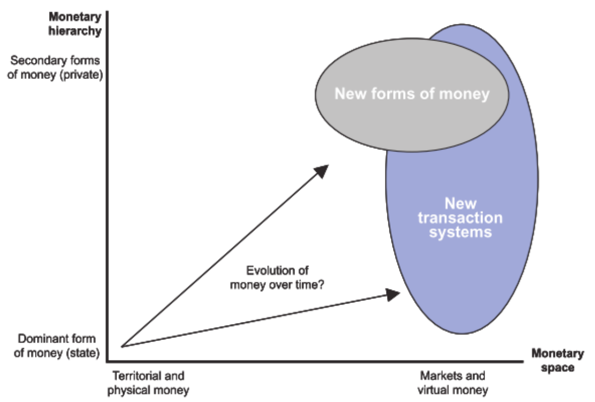

Figure 1. Possible Paths for the Future of Money (Miller, R., OECD 2002)

Case of Bitcoin: Money and the Challenge of the Digital Form:

A 'Problem' of Materiality

Am I the only person in the world who doesn't have bitcoin jangling in a cryptographic wallet? [...]"Are any of them, maybe, lodged between my sofa cushions?"

(Schwartz, 2014)

Bitcoin started as an attempt to eliminate dependence on "trusted third parties" such as banks and governments in the creation and circulation of money (Bitcoin.org, 2014; Nakamoto, 2008). The perceived 'problem' of "trusted third parties" relates to the materiality of fiat money and its precedents, which could be physically seized, stolen or restricted within and across jurisdictions; and whose value could—if a central issuer such as a government chose—be inflated for political or other reasons by increasing supply.

Bitcoin's innovation is to disintermediate the role of "trusted third parties" and reduce the risks imposed by materiality by digitalizing and decentralizing money, that is, by relying on a distributed peer-to-peer network to control the creation and distribution of money. However, in creating a "purely peer-to-peer version of electronic cash" (Bitcoin.org, 2014), a second problem emerges: how to ensure integrity of the system without requiring trust in the decentralized network; specifically, how to prevent the problem of 'double spending' where a user spends the same bitcoin several times by manipulating the digital record (Nakamoto, 2008).

Bitcoin's distinctiveness is its solution to this second problem with public-key cryptography and 'proof-of-work' in a peer-to-peer network to create a 'blockchain'—a sequential and synchronized record of all transactions that is broadcast over the network as a way of keeping a verifiable record. This innovation represents decades of research in Computer Science in the area of Cryptography and Cryptocurrency, particularly the underlying puzzle of 'The Byzantine Generals Problem' (BGP) (see for discussion, Lamport, Shostak, & Pease, 1982).

Computation and Digital Constitution of Money

Two aspects are needed to understand computational and digital dimensions of bitcoin, and consequently, claims by proponents that bitcoin is a "new kind of money". These are: (I) bitcoin as a decentralized digital record of transactions (a sort of virtual ledger that acts as an authenticable record) and (II) bitcoin as a practical solution to an old computational/ algorithmic problem in distributed systems, the BGP, a solution that makes arms-length decentralized interaction possible without the need for counter party trust.

(I)

Bitcoin, unlike object-based money such as commodity, fiat or versions of representative money, is a digital record of transactions whose authenticity can be verified. Bitcoin is public, open-source software that nobody owns or controls, and anyone can partake without approval. The function of public-key cryptography is to secure integrity of this process of digital record entry whereas 'proof-of-work' serves to enable verification and authentication in order to allow secured transactions.

The 'coin' in 'bitcoin', rather than signifying materiality, is a metaphor to describe the virtual 'slots' available in the digital transaction record. There is no material as the name might misleadingly imply, whether by proxy to some underlying physical currency or digitalization of some material form. One buys into the ledger by purchasing one of a fixed number of slots by exchanging something (selling) or with fiat money such as dollars. Similarly, one sells out of the ledger by trading with someone who wants in. Bitcoins are exchanged (or signed over) from one address to another with users potentially having many addresses (public key cryptographic signatures) for transactions.

Each transaction is broadcast to the network and included in the blockchain so that the included bitcoins cannot be spent twice. Roughly, every ten minutes, a set of new transactions called a 'block' is added to the blockchain. After a further brief period, usually an hour or two, transactions are "locked in time" by the large amount of decentralized processing power that grows the blockchain (Bitcoin, 2014).

In order to control the potential for inflation, the number of bitcoins is fixed at a maximum of 21 million by keeping the rate of block creation at roughly six per hour and reducing the number of bitcoins generated per block geometrically by 50% every four years (the rate and algorithms were chosen to mirror the rate of mining commodities like gold) (Bitcoinwiki, 2014).

This process of adding transactions to the blockchain, known as 'mining' enables Bitcoin nodes to reach secured, tamper-proof consensus on transactions in the blockchain. This is also the process by which bitcoins are introduced into the system. Mining is deliberately resource intensive, requiring heavy computational power of several hardware and powerful software machines, in order to control the rate and security of bitcoin creation. To incentivize this resource intensive process within the peer-to-peer network, miners are awarded some fractional value of bitcoins themselves. The role of miners may therefore be seen as a system maintenance and administration one, rather than constitutive of bitcoin itself.

(II)

The problem of being able to transact over a decentralized network without requiring trust or goodwill of the counter-parties is a tricky one that had motivated research in Distributed Systems and Computer Science for several years. The conundrum can be expressed colloquially through the BGP. The original paper to pose the BGP, states it as follows, "[consider] a group of generals of the Byzantine army camped with their troops around an enemy city. Communicating only by messenger, the generals must agree upon a common battle plan. However, one or more of them may be traitors who will try to confuse the others. The problem is to find an algorithm to ensure that the loyal generals will reach agreement" (Lamport, Shostak, & Pease, 1982). As a rule, a lone attempt to invade fails and ends in annihilation of the invaders' armies, making it vulnerable to attack by the other Byzantine generals who also covet and scheme against each other. Moreover, the enemy city's defenses are so strong, that it takes more than half the of the generals' armies attacking simultaneously to overcome. However, if one or more of the generals are untrustworthy and renege then all the attacking armies will be annihilated including the traitors. It is thus a network without trust whose parties must nevertheless cooperate to achieve a shared goal.

For cooperation, the generals communicate without meeting by messages sent and subsequent confirmations received (for lack of trust and in order not to violate the decentralization condition). If a message recipient agrees to a communication, they append a signed and sealed (verified) response to the message, then transmit copies of the combined message to all other generals, asking each to do the same. The result, which will be the agreed and verified battle plan, will be a message chain with signatures and seals of all generals confirming the plan. All other message chains that do not carry all signatures and seals of the generals will be promptly discarded. A problem arises with this arrangement, namely, that if each general sends one message to all generals at the same time there will be a confusingly large number of messages en route, all with conflicting information. Furthermore, some untrustworthy generals may agree to more than one message and transmit more than one message chain, intending to mislead others. The system will thus quickly disintegrate.

Bitcoin's solution to this abstracted computational problem is to add a cost to sending messages in order to slow down the rate of message transmission and at the same time adding an element of randomness so that only one general can send a message at a time. The cost bitcoin imposes is the 'proof of work'—a computation of input into a random hash algorithm consisting of 64-digit alphanumeric string. Bitcoin's input data is the entire blockchain up until the last transaction, and though a hash value can be calculated quickly, only a hash value with 13 zeros in front can be accepted by the system as the 'proof of work'. The random generation of such a hash code is unlikely and takes the whole distributed Bitcoin network about ten minutes of computation before one is generated out of several billion attempts (hence the maximum possible six blocks per hour).

A machine in the network (a general in the BGP analogy) that computes the latest valid hash code takes all previous messages, append their own entry, signs and seals before transmitting to the rest of the network. Public key cryptography tools built into the bitcoin client is what enables the signing and sealing of new transactions into the blockchain. This is the equivalent of the generals' signatures and seals used to verify messages as a way of securing trust and agreement in an otherwise untrustworthy network arrangement.

When the network receives and verifies this updated record, each machine stops its current computation, updates its blockchain and restarts new calculations with this as the latest input. The network therefore constantly synchronizes so that all computers always have the latest blockchain to use as input in computing the next hash code. During the ten minutes the blockchain is updated and synced across all machines in the network, new transactions added to the blockchain in the previous ten minutes are included and synchronized, thereby reconciling the blockchain among all network members. The hashing algorithm is also updated every two weeks to maintain the difficulty and approximate ten minutes it takes to compute as new machines are added to the network.

This 'proof of work' process is what slows the flux of interaction between peers in the network, allows for authenticating and verifying the digital blockchain and thereby solving the BGP. The implications of a solution to this problem are far reaching because it provides a way for anonymous distributed members of a virtual network such as the Internet to exchange digital value in a secure way and leave an authentic, verifiable record of the exchange accessible by the entire network.

Discussion

From Material to Function

This paper suggests that the bitcoin illustration can help answer the question of whether form and materiality are required for function, and specifically, whether form and materiality are required for money to function as money. Aglieta's threefold rationale for understanding the evolution of money—abstraction, centralization, and control is used here as a framework to evaluate bitcoin reconfiguration of money (OECD, 2002,pp.31-68). As outlined, abstraction refers to the changing definitions of the unit of measurement that are becoming increasingly abstract; centralization refers to the processes by which an issuer renders general acceptance to the definition of the unit of measurement within a payment system; control (regulation) refers to the processes by which trust is maintained between debtors and creditors within the monetary system in order to avoid a breakdown of the relational operations of money.

The bitcoin case shows how computation and digital processes reconfigure the entanglement between function, form and materiality along the three rationales of abstraction, centralization and control. This view assumes technology as functional simplification and closure (Kallinikos, 2009c); that is, as a means for reducing money into a function that can be executed to completion (in this case secure, verifiable digital record keeping).

Computation and digital processes achieve this in three main ways. Abstraction occurs by rendering money as a record-keeping digital artifact (the blockchain) rather than a physical object or material token. The blockchain is in constant flux and transfiguration and could hence better be viewed as a computational process of digital transaction entry, authentication/ verification, retransmission and synchronization, rather than a stable artifact. Computational and algorithmic functions, as well as the four characteristic digital properties identified by Kallinikos et al., (2013)—editability, interactivity, reprogrammability/ openness, and distributedness—lie at the core of this processes of abstraction.

Centralization occurs via the blockchain, the central cryptographically secured record of transactions. However, issuing of bitcoin ('mining') is a decentralized process involving the peer-to-peer community. Bitcoin is 'mined' through decontextualizing transaction entry, authentication/ verification and transmission by decentralizing computation over several network actors across space and time, thus becoming "decontextualized conceptual arrangements (templates or matrices) on the basis of which reality is ordered to objects or patterns" (Kallinikos, 2012, p. 82). This process of decontextualization challenges conventional sociomaterial axiom about the relevance of understanding technology in its material and situated context. Given that at any given time, the 'action' of bitcoin mining is happening in various places over several distributed machines and systems, humming away in the background, it is challenging if not impossible to understand technology in light of situated action with recourse to its materiality.

Control (regulation) is reconfigured by disintermediating the formal and material sources of signification, legitimation and meaning of the object of money (sidestepping the so-called "trusted third party" such as government and banks) and relying on a distributed peer-to-peer network of volunteers for issuing, maintaining and securing supply and use. Such material sources of signification, legitimation and meaning include but are not limited to checks, certificates of deposits, bonds, fiat currencies (printed on security paper with the graphical imprints of symbols of power and legitimacy such as presidents, monarchs, pyramids and the like). This process of decentralized control has profound implications for the role of institutions like government and banks in monetary matters and market regulation. Figure 2 summarizes some implications of digital and computational attributes on the three suggested dimensions of evolution of money.

Is bitcoin money? (Implications of reconfiguration of form, function and materiality)

Matter and meaning are not separate elements. They are inextricably fused together, and no event, no matter how energetic, can tear them asunder. Even atoms, whose very name, ἄτομος (atomos), means "indivisible" or "uncuttable," can be broken apart. But matter and meaning cannot be dissociated, not by chemical processing, or centrifuge, or nuclear blast. Mattering is simultaneously a matter of substance and significance [...]

(Barad, 2007, p. 3)

Following the view of money as (1) an abstract social institution constituted by abstract information (verifiable record), shared norms and agreement and a common understanding (2) an entanglement of form, function and materiality in varying amounts at different times and contexts, all undergirded by social signification; bitcoin appears to be functioning as a "kind of money" as claimed by its proponents. Nevertheless, is bitcoin really money? Is Gleick (2010) right in suggesting that the materiality of money does not matter? And is Barad's (2007) claim that matter and meaning are "inextricably fused" applicable in the case of bitcoin? What are the implications of the effects of digital form and computation on abstraction, centralization and control?

		Rationale/dimension of money evolution		
		Abstraction	**Centralization**	**Control**
Attributes of Digital Artifacts	Editability	• Bitcoin dynamic user interface is editable digital artifact synced to wallet and miners.		• Editable Wiki platform to enable coordination (devolved control) through knowledge homogenization in peer-to-peer community
	Interactivity	• Processes between components like 'wallet' and mining are interactive • Front-end processes like buying, selling, storing etc. interactive via APIs	• Centralized entry via interactive artifact (blockchain) accessible through distributed private wallet and constantly maintained by distributed peer-to-peer network of miners	• Wiki platform has interactive forums and chat room for peer-to-peer community enabled by interactivity of digital code
	Reprogrammability/ Openness	• Blockchain is cryptographic record that is constantly updated and secured via networked peer-to-peer computational nodes • Production set to fixed ceiling of 21 million BTC which is maintained by geometrically halving bitcoin per block every four years	• Centralized entry via reprogrammable artifact (blockchain) accessible through distributed private wallet and constantly maintained by distributed peer-to-peer network of miners	• Trust maintained via cryptography program • Openness enables free dynamism of unit of exchange in line with supply and demand
	Distributedness	• Transaction entry, authentication/ verification, retransmission and synchronization enabled by distributedness of digital code	• Decentralized peer-to-peer production ('mining') diminishes need for centralization	• Devolved/ shared coordination by bitcoin community overcomes need for a central control (regulation)

Table 1. Implication of Digital Attributes on the Reconfiguration of Money by bitcoin, an Application of Aglieta (OECD, 2002) and Kallinikos et al., (2013)

It appears that bitcoin's function as money is partial compared to conventional money and there are limitations that the digitally mediated processes of abstraction, centralization and control impose. In particular, bitcoin fails to meet all four basic criteria for money: (1) general use (2) store of value (3) unit of account and (4) Medium of exchange. While it functions as a medium of exchange among a select group, it fails to function as an enduring unit of account and store of value because of two main limitations related to the system and its broad perception.

Systemic problems of bitcoin regard the nature of its abstraction and consequent volatility (Lee, 2013; Tucker, 2013). Bitcoin volatility in 2013 was up to 400% that of a typical stock and its exchange rate about 1000% that of major currencies like the Euro and Yen (Yermack, 2014). Volatility remains a significant drawback because of, among other things, the flux and instability of the digital form. While volatility is partly market-driven, the dynamism of digital form and computation heightens such risks, which are strictly not unique to bitcoin but exists in other complex, distributed electronic transaction systems (e.g., the US stock market's infamous Flash Crash of 2010 brought on by a series of triggers in high frequency algorithm trading (see for discussion, CFTC & SEC, 2010)). Furthermore, the fallibility of the computational systems contribute to volatility. For example, recent losses of over USD 480 million involving the Mt. Gox bitcoin exchange highlighted the potential vulnerabilities in the supposedly hack-proof system (Abrams & Popper, 2014; Dougherty & Huang, 2014).

Such systemic issues drive a faltering perception of bitcoin due to lack of trust. Its complex nature creates a gap in understanding between ordinary people and savvy technologists who are familiar with its complexity (see e.g., Andreesen, 2014). Furthermore, the lack of central authority acts as a double-edged sword by also affecting perceived legitimacy of bitcoin (if no one controls it where does its legitimacy come from; technical arrangements alone? Even if the cryptographic component is 'fool-proof', technical hitches at Mt. Gox and other exchanges raise doubt about the system as a whole). Finally, in the case of cryptocurrency like bitcoin, does diminished materiality hamper trust in its function as money? What about the importance of institutional legitimation? These issues are open-ended but may hold clues for bitcoin's potential to pass or fail the ultimate criterion for money: general use.

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