BEYOND CRYPTOCURRENCIES -

A TAXONOMY OF DECENTRALIZED CONSENSUS SYSTEMS

Complete Research

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Abstract

The advent of Bitcoin in 2009 has not only introduced Cryptocurrencies and lead to a new digitization movement in the financial, especially payments industry but also made way for a new breed of innovative technologies based on decentralized digital currencies. Generally, decentralized consensus systems could change the very nature of how companies, organizations and individuals are built and interact with each other. Decentralized consensus systems, decentralized applications and smart contracts provide the conceptual framework as well as the technological basis to establish predefined, incorruptible protocols and contracts to organize human behavior and interconnectedness. However, the technical protocols and implementations are quite complex and practitioners as well as interdisciplinary researchers not familiar with cryptography, network protocols or decentralized networks are struggling to find access to these concepts and grasp their potential. To fill this gap, we develop a comprehensive taxonomy of decentralized consensus systems in order to provide a tool for researchers and practitioners alike to facilitate classification and analysis of emerging technologies in the field of "Crypto 2.0", the next level of innovation beyond cryptocurrencies.

Keywords: Cryptocurrencies, Decentralized Consensus Networks, Taxonomy, Crypto 2.0, Bitcoin 2.0.

1 Introduction

Automatization, computing and ultimately the Internet have been contributing enormously to growth and wealth of our economies and cultures (Manyika and Roxburgh, 2014). However, a large part of the economy and especially the financial industry is held back by rigid, highly complex and cost inefficient technological infrastructure. At the same time, the financial crisis of 2008 has shown once more that our established, centralized financial and political systems are far from being invulnerable to trust issues and systemic risks that potentially emerge with increased centralization (Helbing, 2012).

This vacuum has been eagerly waiting to be filled by numerous developments and companies, which aim to automate, consolidate and connect some of the tasks which have traditionally been carried out by individuals or groups of organizations.

Some of the topics that have been highly active in this regard and in terms of media coverage include Big Data, P2P-lending and artificial intelligence. Venture capital style and traditional financing in these sectors and financial technology (FinTech) in general has been soaring in recent years emphasizing the relevance of those technologies (Skan et al., 20014). While those topics have been promising extraordinary results and advances, most of them have yet to deliver on their promises and push the ongoing incremental technological progress.

A different stream of development stemming from the fields of cryptographic currencies (frequently referred to as “decentralized digital currency” (Dccy) or “cryptocurrency”) and open source software are decentralized consensus systems (DCS), which are based on peer-to-peer principles rather than central authority and rely on cryptography for network-wide verification (by consensus) of a systems state. In the case of Bitcoin, for example, a consensus is found on an ongoing basis regarding which recent announced transactions represent the current verified state of the system. Their decentralized nature necessitates another defining attribute of these systems, which is their openness in terms of development, management and generally the way the supporting communities are structured. The observed community structures are prevailingly in line with existing literature (Bagozzi and Dholakia, 2006; Xu et al., 2005).

Cryptocurrencies are rapidly becoming more relevant, which is supported by the fact that regulators and international corporations alike are paying close attention or are considering the use of the underlying technological concept of cryptocurrencies. While several regulators such as the Financial Crimes Enforcement Network (FINCEN, 2013), the European Central Bank (European Central Bank, 2012) and the New York State Department of Financial Services (Department of Financial Services, 2014) already published documents in regards to cryptocurrencies, one could argue that regulators in the United Kingdom are already taking the next step. HM Treasury has recently issued a “Call for Information”, which was followed by announcing its intention to increase regulation and establish industry wide standards in regards to cryptocurrencies, as well as increase research funding by GBP 10 million in that respective area (Bank of England, 2015). Furthermore, a Bank of England discussion paper specifically mentions a potential use of the underlying technology of cryptocurrencies for central banks, for example as a way to facilitate interbank settlement (Bank of England, 2015). Recent examples for spikes of interest from the technology industry are Microsoft (Tilley, 2014), Intel (Bello Perez, 2015), IBM, Samsung (Chavez-Dreyfuss, 2015) as well as NASDAQ (Kharif, 2015). The mentioned use cases range from IoT communication (IBM) to exchange system technology dedicated to trading cryptocurrencies on institutional level. While some of the smaller companies and merchants are merely accepting Bitcoins as a payment for their products or services, others are considering the development of payment or settlement solutions based on cryptographic, peer-to-peer technology. A universal bottom line that emerges from these developments seems to be that, while Bitcoin is seen as an interesting proof-of-concept, it is rather the underlying technology or principles, which sometimes are paraphrased as “Blockchain”, “open ledger” or "public ledger" technologies, which represent a potential breakthrough in financial innovation.

Promising applications of DCSs for payment, trading and post-trading already exist and seem to present very interesting alternatives to traditional infrastructure. However, the unlevered potential of DCSs for the financial industry has only started to be unfolded by larger players and institutions of this sector. Decentralized applications (DApp) and smart contracts are suitable to enable versatile, cost effective, low maintenance and - due to the avoidance of central points of failures - robust solutions for almost any kind of application which relies on a network and requires some form of property rights management (Fairfield, 2014). Examples include but are not limited to (micro)payment solutions, decentralized exchanges, financial contracts of arbitrary complexity as well as company shares issuance and trading of the same. Non-Financial applications are decentralized cloud storage, e.g., www.storj.io and www.maidsafe.io and digital content streaming.

Decentralized autonomous organizations (DAO) and companies (DAC) aim at even higher targets by proposing to provide a framework for a new kind of organization or company which are supposed to operate without any human involvement based on a set of programmed, incorruptible rules and in order to orchestrate human and non-human interaction in intelligent ways (Buterin, 2014).

This poses the question whether, aside from the technological revolution DCSs promise, they could also introduce an ideological paradigm shift towards another level of decentralization and openness in our applications, networks, businesses, organizations and societies as a whole.

Such a paradigm shift would also be very much in line with the way open source development (Feller and Fitzgerald, 2002) and sharing culture has been changing the way we interact on the internet and in general.

Regardless of the enormous wealth of concepts and ideas emerging in praxis, little has been written that provides an overall organizational perspective or guidance and what has been written with this focus, following primarily descriptive, journalistic intentions, lacks consistent classification and consolidation on an abstract level. Moreover, the current regulatory scope indicates that the authorities are focused on decentralized cryptocurrencies only. Given the potential and possibilities of DCS, the need for structured knowledge to include decentralized trading platforms or networks is not only helpful in the current phase of information gathering, but is needed as a basis for upcoming regulatory initiatives.

As evoked above, regulators, the technology industry and the academic community are presented with a number of new technological developments and concepts, which, while falling under the category of the general idea of DCSs, are still highly different in nature and potential for application. It is of vital importance that institutions and people involved in the creation, application, assessment and foremost regulation of DCSs are able to determine which kind of system or concept they are dealing with and that they have efficient means to classify said system within the greater context of DCSs. To this end, we think that a taxonomy can represent a valuable tool as a starting point to serve these needs.

Previous research has focused, induced by its technical and mathematical nature, on aspects of the technological infrastructure like security, anonymity, scalability, e.g., in Reid and Harrigan (2011) and Eyal and Sirer (2013) or the resiliency of consensus mechanisms (Karame et al., 2012). Another stream of literature comprises the risks of potential misuse (Brezo and Bringas, 2012). Additionally, we observe that most contributions are limited to specific cryptocurrencies and their features (Antonopoulos, 2014) or primarily cover specific DCS (Swanson, 2014). In summary, we were not able to find a coherent, consolidated and comprehensive classification of emerging applications and services on an conceptual and organizational level that abstracts from the underlying technology. However, such a classification as provided by a taxonomy, can serve as a basis for strong research, theory and hypothesis development as well as for understanding causes of diversity and similarities of organizations or concepts (Rich, 1992). Thus, equipped with knowledge structured on an abstract level, researchers will be enabled to identify and understand forces at work behind organizational developments in the emerging industry. We aim to fill this research gap by answering the question: What are the archetypes of decentralized consensus systems and how can they be classified?

Consequently, the goal of this work is to propose a taxonomy for decentralized consensus systems. Put differently, we aim to equip both academics and practitioners with an appropriate classification framework to base future research upon, i.e., develop theories, derive ideas on decentralized consensus systems as well as their applications, services or any higher layer organization based on these innovative technologies.

Due to the novelty of some concepts and the underlying technologies, we provide an overview of recent developments and related literature in chapter two. Chapter three is dedicated to our taxonomy development process. In chapter four we reflect on our research approach and our findings respectively, chapter 5fivecomprises our conclusion and research outlook.

2 "Crypto 2.0": Technologies, Concepts & Communities

2.1 A chronological review of concepts underlying cryptocurrencies

Although the idea of decentralized transaction systems is far from new (Garcia and Hoepman, 2005), only fairly recent technology developments such as advances in applications of cryptographic methods and peer-to-peer networks have been pushing the general concept forward. Many of these developments are rooted in the progress of cryptographic currencies, lead first and foremost by Bitcoin.

Bitcoin was first described in a technical paper in 2008 and subsequently implemented in 2009 by a presumably pseudonymous individual or group calling himself or themselves Satoshi Nakamoto (Nakamoto, 2008). It is a decentralized payment system tightly coupled with its inherent currency. Bitcoin relies on a network consisting of users, who contribute to the system's operations and security by having a client software running on their local computer.

The process of verifying a set of transactions in a block by means of solving a complex cryptographic computation is conducted by the network's nodes. The work, i.e. computation time, based on the transactions contained in the block is hard to fake but easy to verify. Hence, the verification of the block's transactions is considered secure as long as the network as a whole is not corrupted (Bradbury, 2013). This method of proving authenticity of a historical transaction is called "proof-of-work" (PoW). The blocks are collected on a public ledger, called "Blockchain", which is stored on each network participant's computer. The underlying proof-of-work algorithm is parameterized in such a way that blocks are created roughly every 10 minutes in the case of Bitcoin. The block creation process, which rewards the solver of the computational challenge with the networks inherent currency, is called "mining". Other types of verification for a general ledger or Blockchain have been proposed, such as proof-of-stake (PoS) and Voting to overcome weaknesses of the PoW approach (Nakamoto, 2008; Zhang, 2014).

Some of the inherent properties of cryptocurrencies make the underlying technology an appealing candidate for amending or eventually displacing incumbent payment and transaction infrastructure. Among these are transaction speed (Karame et al., 2012) and security (Grinberg, 2011), scalability and, most important, lower costs and entry barriers (Barber et al., 2012). These low entrance barriers and costs are essential building blocks for the next level of global financial inclusion and further emphasize the importance of these developments.

The general decentralized way in which the network and ongoing development of it is organized may also reduce the amount of central points of failure, which should increase confidence in the system. However, the issues of trust and confidence pose yet to be solved problems and require further research in order to assess whether decentralized systems could potentially be superior to centralized ones. At least in some areas.

Against the backdrop of tremendous increases of price and market capitalization, the community around Bitcoin quickly spawned alternative cryptocurrencies as well as an extensive ecosystem of third party escrow services, (centralized, i.e. operated by a single organization) exchange platforms, Bitcoin-based derivatives and other trading practices. Alternative cryptocurrencies, also sometimes called "Altcoins" are built using Bitcoin's code base and vary in some of the parameters or hashing algorithms. Some of the exchange platforms or services already theoretically support advanced financial functions such as derivatives, margin trading and equity financing albeit in a rudimentary way.

However, the pseudonymous nature and regulatory remoteness of the larger part of the cryptocurrency sphere has been keeping most serious investors or financial institutions reluctant to invest or engage in the area.

On one hand side, this has been leading to Bitcoin related firms trying to offer fully legally compliant services, thereby taking a step back from the more radical concept of a decentralized transaction system. Examples include “Circle” and German bank “FIDOR Bank AG” which offer bank accounts denoted in Bitcoin and “Coindesk”, which partners with e-commerce companies to enable payments via Bitcoin for end users.

The other current of development is taking a very different direction. Instead of “re-centralizing” some of the functionality cryptocurrencies provide, those systems and protocols aim to decentralize an even larger part of financial infrastructure.

2.2 From Cryptocurrencies to Decentralized Consensus Systems

Cryptocurrencies themselves lack the versatility and functionality, which is necessary to facilitate more complex financial applications. Consequently, the logical step to also decentralize more complex applications does not seem to be far-fetched (Fairfield, 2014). These decentralized consensus systems would then theoretically combine the speed, security, and cost-efficiency of cryptocurrencies with the versatility and functionality of traditional systems.

Differentiating this type of decentralized consensus systems from cryptocurrencies is not straightforward, however generally these DCSs should provide the user with the ability to create and exchange multiple types of assets, which should differ and be dynamic in terms of properties compared to the mono dimensionality of cryptocurrencies; e.g. there usually is just one “asset”, namely the currency which is static in nature.

The more dynamic the properties of these assets are, the more likely one could call them “smart contracts”, which is a concept that has been initially introduced by (Szabo, 1997). While his definition is extremely broad and could encompass all kinds of automatic or even artificially intelligent properties, some functionalities such as automatic dividend or coupon payment and hard-coded links to data feeds are also already dynamic in nature.

Starting from late 2012, several of these DCSs, which also are sometimes classified as “Bitcoin 2.0” (Evans, 2014) or "Crypto 2.0" (Brokaw, 2014) have emerged. Some of them are using fairly similar and some are using very different technical approaches and organizational structures. From a technical point of view there seem to be two major categories, one being independent cryptographic systems with their own Blockchain implementation, the other type of systems being built as a second or third layer on top of Bitcoin or any other Altcoin.

From an organizational standpoint the field is divided into for-profit and not-for-profit types of organizations who maintain and foster development of the respective systems. Generally, the decentralized, peer-to-peer nature of DCSs seems to permeate to the projects’ developers and supporting communities. Most of the projects have decided to use open source licensing and are generally open to community commitments of various sorts. However, there seem to be differences in the way these communities are structured, with some being flat and completely open, some employing a tiered approach and some being more closed in nature.

Another difference lies in the way the systems initially distribute the networks “native” currency. While more profit-oriented organizations and companies initiate a “crowd sale”, in what is comparable to a stock IPO, some other systems, which are arguably more committed to the idea of openness and decentralization, distribute the currency by “burning” Bitcoins. This implies sending Bitcoins to a public address to which provably nobody has the private key, effectively destroying those Bitcoins in the process.

The first major implementation of such a system, which allows the creation and trading of more advanced financial contracts and assets appears to be the “Master Protocol” which is described as being a “[...] layer between the existing Bitcoin Protocol and users’ currencies [...]” (Willet, JR et al., 2013). It also seems to feature a working decentralized exchange for trading user created assets or digital currencies (Willet, JR et al., 2013).

While there do exist some other implementations which are built on top of Bitcoin such as Counterparty (Krellenstein, 2014) and Colored Coins (Assia et al., 2012), the majority of newer implementations appears to be relying on separate decentralized consensus networks. Examples of such systems are Bitshares, Nxt and Ethereum. These systems rely on networks and the Blockchain concept similar to Bitcoin, which are based on cryptographic principles such as Proof of Work, Proof of Stake and Voting in order to ensure network, i.e., consensus security. These systems are frequently referred to as "Metacoins" (Antonopoulos, 2014; Franco, 2014; Swanson, 2014) .

An example of an implementation which is supported by a for-profit organization is Ripple. While also being a decentralized transaction system of pseudonymous nature, Ripple is in various ways unique and separate from the rest of the systems portrayed. For one, it is not based on Bitcoin's cryptographic principles but rather on what is called a "consensus process". The consensus is met among a group of servers with each of them being an "[...] entity running the Ripple Server software (as opposed to the Ripple Client software which only lets a user send and receive funds), which participates in the consensus process." (Schwartz et al., 2014). An overview of the relationships of the introduced concepts and organizational structures they are embedded in is depicted by figure 1 in the appendix.

2.3 Related Literature

As outlined above, Bitcoin and cryptocurrencies in general paved the way for new technologies such as the Blockchain and led to innovative concepts or rendered old ones technologically feasible, e.g., the formal idea of smart contracts proposed by (Szabo, 1997). Besides the practical impact and its implications, cryptocurrencies initiated a new (research) domain that is already populated by a rich palette of different concepts, technologies and applications. Academic literature is vast and continuously growing, however only with respect to specific perspectives, i.e., those focused on technical features. A different perspective that has been addressed is regulation and legal classification of cryptocurrencies. Governmental institutions have long been struggling for official statements regarding tax related questions and general legal classifications (European Central Bank, 2012; FINCEN, 2013; Casey, 2014). Furthermore, the most recent applications and innovations were proposed by the community or in white papers of companies in 2013 and 2014. Namely decentralized autonomous organizations (DAO) first mentioned by (Buterin, 2014) and Decentralized Applications (DApps) introduced by (Johnston, 2014). Detailed descriptions of public ledger technologies can be found in the journalistic work of Antonopoulos (2014), Franco (2014) and Swanson (2014). They provide detailed descriptive and anecdotal-evidence based explanations of the technology and its usability. The reader can obtain knowledge about how a blockchain actually works, how he can trade or manage tokens of a cryptographic currency and what different types of services are provided by Metacoin platforms. As a means of technical classification Swanson (2014) provides a diagram that summarizes the different ledger and consensus mechanisms types. However, we rely on these works as a starting point and extend the obtained information by incorporating white papers of technology providers and community social media channels (e.g. www.github.com) to include the most recent technological developments and to achieve a comprehensive taxonomy. To the best of our knowledge, academic literature is lacking a comprehensive classification and with this work we aim to fill this gap.

3 A Taxonomy of Decentralized Consensus Systems

Taxonomies and classification frameworks in general are an established instrument in information systems and other research disciplines serving the fundamental need to structure knowledge and classify objects belonging to specific domains (DeLone and McLean, 1992; Farbey et al., 1995; Gregor, 2006; DeLone and McLean, 1992). We focus on the fast growing and far from being established knowledge about applications that incorporate and push forward the concepts that emerge in the domain of decentralized consensus systems. As outlined in the previous sections, these systems are considered the next generation of systems and applications which utilize and push the boundaries of the concepts and technologies introduced by cryptocurrencies.

The overall purpose of the proposed taxonomy is to provide guidance for practitioners and researchers who are not rooted in computer science or mathematics, but need a tool for quick classification of allegedly innovative concepts, artifacts and applications. Plenty of work has been dedicated to analyze and write about technical modifications and properties of the underlying technology. However, a driving motive is also the rationale behind the question of why the taxonomy should fulfill the quality properties of being "precise" and "comprehensive". In the case the taxonomy possesses these quality properties, a concept that cannot quickly be classified by the taxonomy (and its user) could be considered innovative and most likely deserves the user’s attention. A practical example could be a venture capitalist or other type of creditor, i.e., supporter who needs to classify a proposed concept.

Another, maybe even more important motivation is to propose a taxonomy that facilitates abstraction from the established terms Bitcoin, cryptocurrency, digital currency and the blockchain concept. They are most likely too narrow concepts for classifying the next generation of platforms and applications. Such an abstract perspective could provide substantial utility for regulators who have to make far-reaching regulatory decisions. Their decisions are supposed to be considered valid within a mid- to long-term time frame and should there be well-founded on a robust knowledge base. It could also be a necessity to tailor a regulatory framework for certain subsets and classes of businesses or services in this new domain. A classification that is delineating different types of services or businesses on an abstract level is hence suitable when regulatory authorities are facing these needs.

Therefore, the taxonomy should also provide abstraction from specific implementation details or economic parameterization as these could easily change without changing the degree of innovation of the technology. Put differently, the taxonomy is not intended to differentiate between different cryptocurrencies that differ from each other with respect to technical/economical, supply algorithms, anonymity and so on. Our approach to develop this taxonomy is described next.

3.1 Taxonomy Development in Research on Information Systems

Recent work on taxonomies in information systems includes the work of Nickerson et al. (2013) which we refer to for two reasons. On the one hand, they conduct an extensive literature review on taxonomy development with an inter-disciplinary scope. On the other hand, they derive a taxonomy development method suitable but not limited to research in information systems. Their method is designed to incorporate desired aspects extracted from a diversified set of taxonomy development methods of research disciplines such as Business Administration and Biology. The method provides predefined steps in order to avoid intuitive development. For the development of our taxonomy of DCSs we rely on the method proposed by Nickerson et al. (2013). We briefly review the method and describe our development procedure with rather fine granularity to make our decision process as transparent as possible.

The methodology review is covered by the remainder of this section whereas the actual development procedure is described in the next section.

The methodology we apply is split up into seven steps. Five of these steps (steps three to seven) are performed iteratively as is depicted by figure 2. We will give a brief recapitulation of steps 1-3 for the ease of understanding of our development process initialization. We refer to the related paper of Nickerson et al. (2013) for a detailed description of the more intuitive steps 4-7.

Two parameters need to be defined upfront in step 1 and step 2 respectively. In step 1, a meta-characteristic is to be defined. A meta-characteristic should be chosen in order to avoid naive empiricism, that is starting to analyze an arbitrary set of characteristics in reliance on pure chance that any structure will be revealed or identified during the search process. It is supposed to guide through the selection of characteristics as every characteristic included during the development process should display a logical tie with the meta-characteristic. Hence, the selection of the meta-characteristic is crucial for the final outcome of the taxonomy. The meta-characteristic is therefore tightly coupled with the purpose definition as well as the intended target group of the taxonomy. This implies that a clear understanding of the target group and the purpose of the taxonomy are helpful building blocks for identifying a meta-characteristic. To comply with this best practice, we will make our target group and purpose explicit and base our choice of the meta-characteristic on the same.

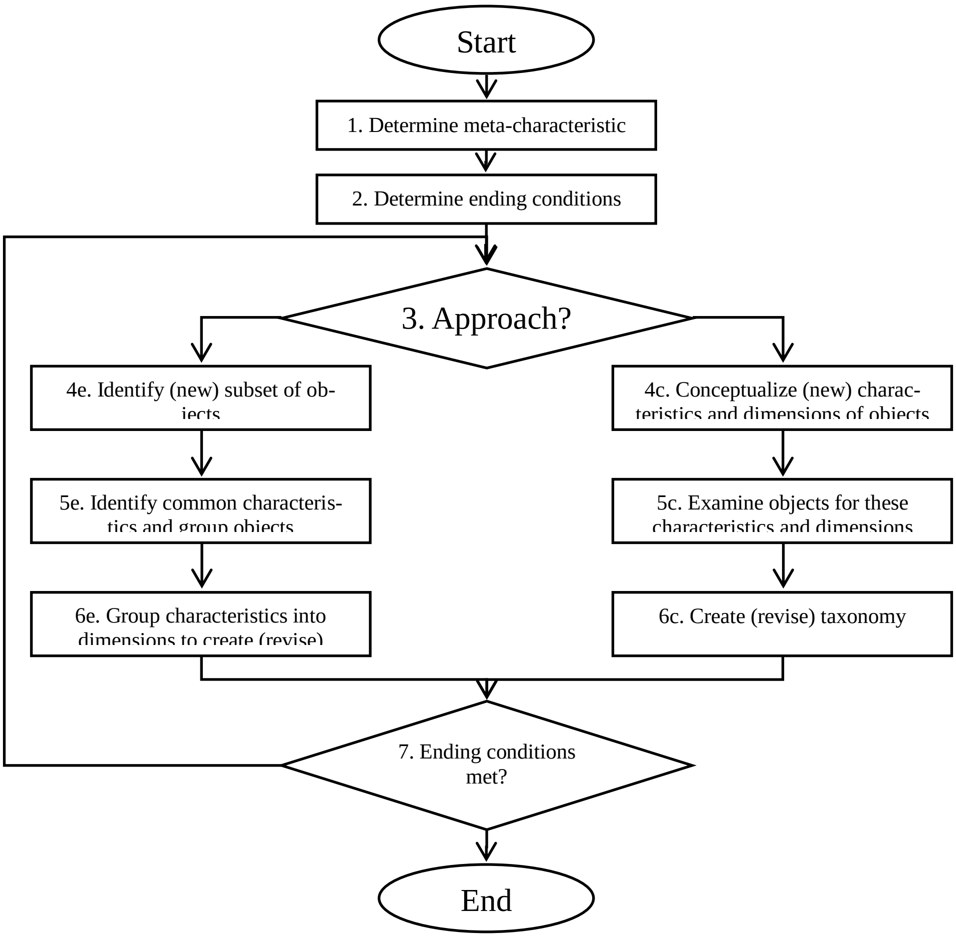

Figure 2. The taxonomy development method proposed by Nickerson et al. (2013).

Step 2 prescribes the definition of ending conditions which are controlled after each iteration and signal to leave the iterative development process if they are met. The authors of the method distinguish between objective and subjective ending conditions. Their objective conditions are presented by Table 1 and their subjective conditions by Table 2 in the appendix. For a more detailed explanation we refer to the original paper of Nickerson et al. (2013). They are general in nature, suitable for our intentions and easy to understand, thus we decide to stick to these ending conditions.

For step 3, selection of the analysis approach, two approaches are available: conceptual or empirical. According to Nickerson et al (2013) the empirical approach is considered suitable if there is domain specific data available, e.g., from literature sources. When following this direction, the researcher selects a set of objects to be classified according to existing literature and analyses common characteristics.

The conceptual approach, in contrast, is suitable if data is scarce but the researchers have profound knowledge of the domain. It requires the researcher to apply his or her own understanding of the domain to identify appropriate dimensions for classification. The result should be capable of covering all objects that could conceptually fit into the scope of the taxonomy spanned by the meta-characteristic.

In the case that researchers have data and knowledge at hand, it is up to them to choose the approach.

3.2 Description of the Taxonomy Development Process

The taxonomy development is based on three types of resources. The first type we rely on are the technological white papers of the most popular platforms and their proposed concepts. The selection of platforms is based on the three journalistic books (the second type of resources) introduced in section 2.3. The third type of information is obtained from user generated content or papers published by community members, e.g., developers. Especially due to the novelty of the subject, no specific research was available and we thus had to rely on the community generated resources to get a fundamental impression of the concepts and the respective features or attributes. The selection of each resource is based on the fact, that these sources, as of this writing, are the only resources that we could find about the covered concepts and technologies. A descriptive and extensive overview of resources is provided in table 3 in the appendix.

Based on these resources we subsequently describe our application of the taxonomy development method. We provide an abbreviated protocol to give insights why certain dimensions and characteristics are selected, while others might be neglected. The presented protocol comprises 3 iterations. Some refinement iterations of minor importance were skipped for the sake of brevity. Before we describe the development, we set up the required parameters as described above.

Target Group and Purpose Definition

In accordance with our definitions at the beginning of this section, the target group consists of practitioners and researchers looking for an easy to use tool for non-technical concept and system classification in the domain of decentralized consensus systems. The purpose is further to give them a tool at hand that is capable of providing a classification with a reasonable level of abstraction from too narrow technological terms as well as single implementation specific naming.

Step 1: Determine meta-characteristic

As a meta-characteristic we choose conceptual properties of decentralized consensus systems, especially applications based on this type of system.

Step 2: Determine ending conditions

We rely on the ending conditions described by Table 1 and Table 2 (see appendix).

Steps three to seven are performed iteratively. Dependent on our selection of the empirical or the conceptual approach, for subsequent steps four to six we indicate by an "e" that we are following the empirical and by a "c" that we are following the conceptual approach respectively.

The iterative development process terminates if the ending conditions are collectively fulfilled after an iteration. As a starting point we rely on the work of Antonopoulos (2014), Franco (2014) and Swanson (2014) in order to extract characteristics that are consistently reported by these authors. Frequently, pairwise distinguishing features are provided for more established objects and concepts, for example features that draw the line between Altcoins and Altchains. However, some concepts are not reported or still subject to a vivid, ongoing discussion of the community, e.g., decentralized applications. In this case, we draw on the descriptions in the books and add information from conceptual white papers of projects focusing on the respective type of concept as well as the community discussion platforms in order to derive a more comprehensive classification. Whenever possible or necessary, we try to unify the classifications of the published literature as well as the community inherent views. This way, we shape the essence of those different types of resources into a single taxonomy in order to achieve comprehensives as well as robustness.

Iteration 1:

Step 3: We select the empirical approach as the first iteration is based upon the information retrieved from the available books.

Step 4e: Identify (new) subset of objects

A first subset of objects is the subset of cryptocurrencies. We refer to decentralized digital currencies (Dccy) as decentralized consensus must not longer necessarily be based on cryptographic concepts. Many Dccys are summed up by the alias Altcoin, which emerged quite early with the first projects that were forking from Bitcoin. At the point of writing there are more than 500 different cryptocurrencies (http://coinmarketcap.com). We only consider the abstract concepts of Altcoins and Altchains to differentiate between Dccys. Altchains differ from Altcoins by the level of code variation (https://en.bitcoin.it). Often the terms are used as synonyms. The total subset hence covers, for example, Bitcoin, Peercoin, DarkCoin, Peercoin and Litecoin.

Step 5e: *Identify common characteristics and group objects*

A common characteristic is the fact that both Altcoin and Dccy are reliant on different implementations of consensus mechanisms, either implemented from scratch or as code forks from other projects and hence can only vary with respect to fine grained technical implementation details. Hence, we identify the characteristics of being derived or written from scratch. It is worth noting, that from scratch does not refer to the lines of code itself, but the inherent logic of the code. Put differently, porting the same implementation into another programming language or refactoring of classes does not count as "from scratch". Furthermore, at this point we decide to introduce a hierarchical characteristic, i.e., one object can rely on another. According to our previous explanation, an Altchain has forked from another coins code base but only shares the most central concept, i.e., the consensus mechanism, which would thus be the underlying. In contrast, an Altcoin is also forked from another implementation but has, so to say, the Dccy or Altcoin as underlying it forked from.

Step6e: Group characteristics into dimensions to create (revise) taxonomy

We group the characteristics into the dimension "Code Base" and "Underlying". Code base comprises the characteristics "from scratch" & "derived". Underlying comprises consensus mechanism and Dccy.

Step 7: Ending conditions met?

At least on objective condition is not met as we added two dimensions as well as characteristics so we need another iteration.

Iteration 2:

Step 3: We select the empirical approach. In this iteration, information from the available books is supplemented by information extracted from white papers published by technology providers.

Step 4e: Identify (new) subset of objects

For the identification of the next subset of objects we rely on the chapters (Antonopoulos, 2014; Franco, 2014; Swanson, 2014) that contain referred to as "Metacoins", "Bitcoin 2.0" (Swan, 2014) or "Crypto 2.0" (Brokaw, 2014) applications. The terms Metacoin or Bitcoin 2.0 refer to applications that offer additional services besides value transaction and focus on protocol features that are extendible and reusable for higher level applications. For example, smart contracts and related concepts that have been briefly introduced in section two. Metacoins have an ALT as underlying and exploit the verification and consensus mechanisms of these for provision of more abstract services on protocol level. Another concept that has been introduced only recently (October 2014) by Back et al. (2014) is "pegged sidechains". this concept introduces the possibility to operate a (Bitcoin) based Altchain in parallel to Bitcoin and couple (called "peg") its value to that of Bitcoin by providing a mechanism to transfer tokens between both systems.

Step 5e: Identify common characteristics and group objects

Common characteristics are the service focus the systems offer, a new level of underlying, i.e. completely being based on an Altchain and the coupling of value to another DCSs token and the actual usage of the inherent token, i.e., primarily for actual value transaction purposes (external value of the token itself, not contracts possibly build upon it on protocol level) or primarily for verification for protocol level based services.

Step6e: Group characteristics into dimensions to create (revise) taxonomy

First, Altcoin is a new characteristic of dimension "Underlying". Second, we distinguish between external; for example on a secondary market, i.e., an exchange) and pegged valuation and add the dimension "Valuation". Third, in the dimension "Token Usage" we differentiate if the token is used for transaction of its inherent value or for verification of higher level services.

Step 7: Ending conditions met?

At least one objective condition is not met as we added two dimensions as well as characteristics so we need another iteration.

Iteration 3:

Step 3: We select the conceptual approach as we are retrieving conceptual knowledge retrieved from own platform analyses as well as ongoing discussion and papers published by community members.

Step 4c: Identify (new) subset of objects

Driven by the interesting and ongoing discussions within the communities, we decide to include this information to capture the next level of concepts that is currently emerging. The objects identified in this step are the concepts of Decentralized Applications (DApp) as proposed by Johnston (2014), Decentralized Autonomous Organizations (DAO) and their subclass decentralized autonomous corporations (DAC). The latter two were introduced by Buterin (2014) and are also described by Swanson (2014). Finally, we consider Ripple (https://ripple.com) as a DCS that is implemented by a for-profit organization.

Step 5c: Identify common characteristics and group objects

They all have in common that they are built on top of a Metacoin-type consensus system and exploit dedicated protocol features, hence they have the concept of a Metacoin as underlying. However, they primarily focus on the application built upon the Metacoin DCS. That is, differences between the objects arise from the service focus they have. We distinguish between being focused on provision of a protocol level service, i.e. special protocol features to facilitate the development of applications for others user, or being focused on abstraction from protocol level features and represent an application on top. The lowest level would be the pure transaction of value represented by tokens. It is worth noting that these characteristics differ from the "Token Usage" characteristics that were introduced in the previous iteration. For example, a DAC is focused to provide a service as application based on a protocol but uses the tokens for actually transferring value, i.e. shares of the decentralized corporation. Another set of characteristics that distinguishes the objects are the types of community they are developed and maintained by. One end of the scale is represented Ripple. Ripple as a system, in contrast to the others, is owned by a company and hence has a sort of central authority that provides the DCS as a service. In contrast, according to its initial definition, a DApp must be developed and controlled completely decentralized by its users, each user having the same rights and being open for anyone to participate. The most frequent case, however, is a tiered development community, as is described in the literature as well (Bagozzi and Dholakia, 2006; Di Bella et al., 2013; O’Mahony and Ferraro, 2007).

Step 6c: Group characteristics into dimensions to create (revise) taxonomy

First, we add Metacoin as an underlying to dimension "Underlying". Second, we add the dimension "Community" comprising the characteristics "Flat", "Tiered" and "Centralized". Third, we group the characteristics token focused, protocol focused and application focused. The corresponding dimension is named "Service Focus".

Step 7: Ending conditions met?

Besides the fact that we added dimensions and characteristics, we find all other objective conditions to be satisfied. We have analyzed a comprehensive set of objects (condition 1), did not merge or split (2) objects, have at least one object per dimension (3) and obtained unique characteristics (6), dimensions (7) as well as cells (8). According to our judgement, the subjective ending conditions are met at this point. However, the subjective conditions are more difficult to evaluate as they are subject to individual perceptions and can only be justified by argumentation. They are therefore made part of the discussion of our results in the next section. The final taxonomy is presented in table 4.

		Decentralized Consensus Systems						
Dimension	**Characteristic**	**Dccy**	**Altcoin**	**Sidechain**	**Metacoin**	**DAO**	**DAC**	**DApp**
Underlying	Consensus	x						
	Dccy		x					
	Altcoin			x	x			
	Metacoin					x	x	x
Valuation	External	x	x		x	x	x	x
	Pegged			x				
Community	Flat							x
	Tiered	x	x	x	x	x		
	Centralized						x	
Service Focus	Token	x	x	x				
	Protocol				x			
	Application					x	x	x
Code Base	Scratch	x						
	Derived		x	x	x			x
Token Usage	Transaction	x	x	x		x	x	
	Verification				x			x

Table 4. Taxonomy of Decentralized Consensus Systems.

4 Discussion

Comprehensiveness is achieved by considering existing classifications and descriptions and incorporation of concepts that bubbled up only recently in community social media channels and are subject to ongoing discussion. We argue that the proposed taxonomy is applicable for any conceptual level objects of the domain and is relying on the infrastructure of a decentralized consensus system. Due to the moderate number of six dimensions and easy to understand characteristics we consider the taxonomy to be concise and easy to use as was intended. Given the deliberate abstraction from limiting terms and concepts, we believe to have achieved a certain level of robustness and also made the taxonomy extendible. Furthermore, the abstraction from most technical features and the selection of concepts which are rather comprehensible for users that might not be too familiar with the knowledge domain increase the explanatory quality of the chosen characteristics and dimensions.

We faced minor hurdles during the development process. It was not always straightforward to focus on the non-technical aspects only. This is driven by fact that many Altcoins and platforms differentiate themselves based on suggested technical improvements or slight variations of services they offer. Helpful in solving this issue, besides being guided by the meta-characteristic, was to recall the target group and the intended purpose. Based on this experience and as a methodological contribution, we suggest adding the predefinition of target group(s) purpose as an explicit first step (Step 0) of the methodology. We argue that this would improve the methodology due to the circumstance that a crucial and helpful parameter is incorporated at the beginning of the actual development process and thus more present and emphasized in the researchers mind while working out the taxonomy.

The actual helpfulness of the taxonomy and its robustness regarding future development can hardly be evaluated by the authors themselves at this time. This is a clear limitation of our work. Hence, a welcome scenario would be that other researchers and practitioners apply the taxonomy and evaluate whether the it adds value during their own endeavors into the sphere of cryptocurrencies and decentralized consensus systems.

Other limitations of this work are that we do not apply statistical methods like clustering algorithms and rely on a rather small sample of platforms. The reasons for this decision are the following. Applications based on the most promising concepts like smart contracts are in very early stadiums of implementation at the time of writing. Hence, the available information to build empirical research upon is quite scarce. Fortunately, the development cycles of technology startups and development communities nowadays are extremely short and the announced applications likely to mature within a short time window. We take these limitations to shape the future perspective of our own research.

We argue that the resulting taxonomy points out structural and hierarchical interdependencies and possible influential economic or organizational connections that are yet to be examined. The most interesting example is the crucial role of the interplay of the decentralization of the development community and the intended service the developed decentralized application or organization is about to provide. Drawing on the created structural knowledge, a fast diversity of new research perspectives can be generated. Hence, we contribute to the knowledge on conceptual and organizational structures in the innovative and yet to be discovered field of decentralized consensus systems and their environments. Practitioners can use the taxonomy to identify truly innovative concepts or services by controlling for their fit with the taxonomy without substantial alterations. Regulatory authorities could incorporate the obtained structural knowledge for tailoring regulatory initiatives and as information foundation.

5 Conclusion & Outlook

The field of cryptographic currencies, peer-to-peer transfer systems and more generally de-centralized consensus systems is still young and is growing rapidly. New concepts, implementations, platforms and organizations spawn on an almost daily basis. Even if some of the early projects may not survive the test of time in their original form, the underlying innovative technology and the concept of decentralization present tremendous opportunities for the future. When analyzing or developing new systems of this sort, classification and an overview about how the supposedly innovative technology fits into the existing landscape can bring a vital amount of clarity to practitioners working in the financial or information systems fields. We propose a taxonomy that we consider to be comprehensive, concise, robust and extendible and therefore a helpful and easy to use tool for practitioners and researchers alike. They can quickly retrieve or classify information and draw upon a suitable tool to describe and analyze the developments and businesses that are building on decentralized consensus systems.

For our future research we plan to evaluate and improve the proposed taxonomy in two possible ways.

The next logical step is gathering a comprehensive data set and conduct a profound empirical analysis of the innovative applications, products and services that emerge in this sector. By empirically testing and improving the taxonomy with means of statistical methods, .e.g. algorithms for cluster analysis as applied by Haas et al. (2014) or Malhotra et al. (2005) we are eager to push the understanding and knowledge of these highly interesting concepts and their environments further.

We also consider an extensive survey among community members and practitioners to test and validate our results. We are keenly interested in feedback from our target groups and are looking forward to exciting new developments and innovations in the domain of decentralized consensus systems .

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Appendix

Objective ending conditions	**Comments**
All objects or a representative sample of objects have been examined	If all objects have not been examined, then the additional objects need to be studied
No object was merged with a similar object or split into multiple objects in the last iteration	If objects were merged or split, then we need to examine the impact of these changes and determine if changes need to be made in the dimensions or characteristics
At least one object is classified under every characteristic of every dimension	If at least one object is not found under a characteristic, then the taxonomy has a 'null' characteristic. We must either identify an object with the characteristic or remove the characteristic from the taxonomy
No new dimensions or characteristics were added in the last iteration	If new dimensions were found, then more characteristics of the dimensions may be identified. If new characteristics were found, then more dimensions may be identified that include these characteristics
No dimension or characteristics were merged or split in the last iteration	If dimensions or characteristics were merged or split, then we need to examine the impact of these changes and determine if other dimensions or characteristics need to be merged or split
Every dimension is unique and not repeated (i.e., there is no dimension duplication)	If dimensions are not unique, then there is redundancy/duplication among dimensions that needs to be eliminated
Every characteristic is unique within its dimension (i.e., there is no characteristic duplication within a dimension)	If characteristics within a dimension are not unique, then there is redundancy/duplication in characteristics that needs to be eliminated. (This condition follows from mutual exclusivity of characteristics.)
Each cell (combination of characteristics) is unique and is not repeated (i.e., there is no duplication	If cells are not unique, then there is redundancy/duplication in cells that needs to be eliminated

Table 1. Objective ending conditions. Source: Nickerson et al. (2013).

Subjective ending conditions	**Questions**
Concise	Does the number of dimensions allow the taxonomy to be meaningful without being unwieldy or overwhelming? (A possible objective criteria for this condition is that the number of dimensions falls in the range of seven plus or minus two; Miller, 1956.)
Robust	Do the dimensions and characteristics provide for differentiation among objects sufficient to be of interest? Given the characteristics of sample objects, what can we say about the objects?
Comprehensive	Can all objects or a (random) sample of objects within the domain of interest be classified? Are all dimensions of the objects of interest identified?
Extendible	Can a new dimension or a new characteristic of an existing dimension be easily added?
Explanatory	What do the dimensions and characteristic explain about an object?

Table 2. Subjective ending conditions. Source: Nickerson et al. (2013).

Type of resource	Concepts covered	Resources
Books	Cryptocurrency, Altcoin, Metacoin	Antonopoulos (2014), Franco (2014), Swanson (2014)
Platform white papers and community content	Metacoin, Sidechain, Smart contract, Decentralized Autonomous Corporation, Decentralized Autonomous Organization	Assia et al. (2012), Back et al. (2014), Buterin (2014), Johnston (2014), King and Nadal (2012), Krellenstein (2014), Larimer (2014), Lee (2014), Nxt Community (2014), Schwartz et al. (2014), Szabo (1997), Willet, JR et al. (2013)

Table 3. Structured overview of resources for the taxonomy development.

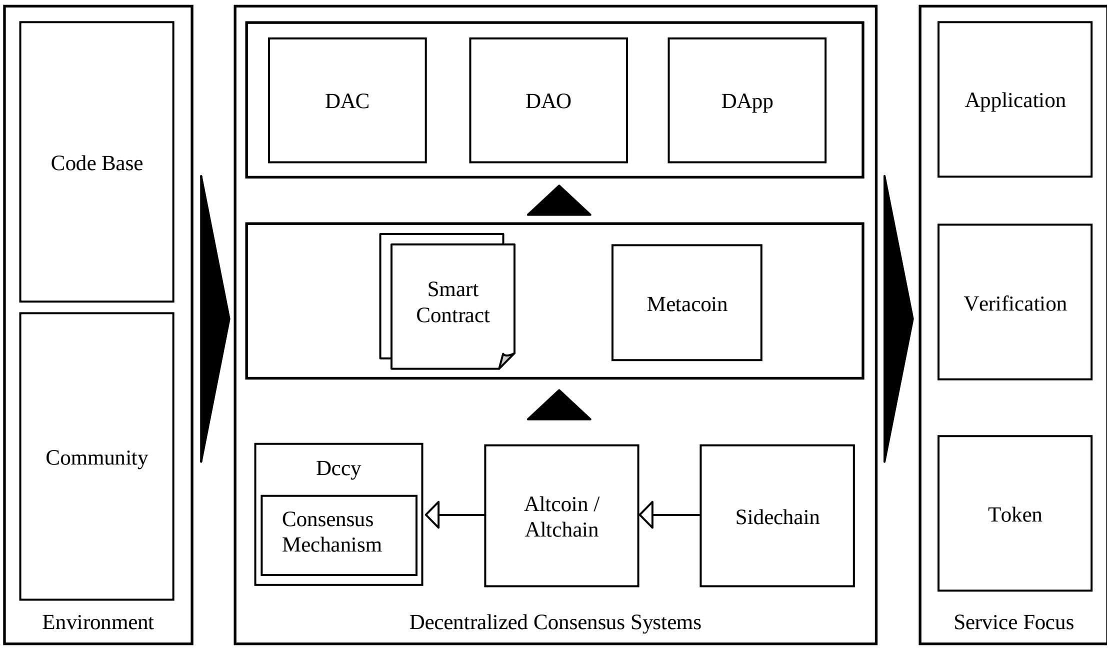

Figure 1. Overview of decentralized consensus systems and their relationships.