BLOCKCHAIN DEMYSTIFIED: A TECHNICAL AND LEGAL INTRODUCTION TO DISTRIBUTED AND CENTRALISED LEDGERS[+]

Jean Bacon[*]
Johan David Michels[**]
Christopher Millard[***]
Jatinder Singh[****]

Cite as: Jean Bacon, Johan David Michels, Christopher Millard & Jatinder Singh, *Blockchain Demystified: A Technical and Legal Introduction to Distributed and Centralised Ledgers*, 25 RICH. J.L. & TECH., no. 1, 2018.

[+] This paper has been produced by members of the Microsoft Cloud Computing Research Centre, a collaboration between the Cloud Legal Project, Centre for Commercial Law Studies, Queen Mary University of London and the Department of Computer Science and Technology, University of Cambridge. The authors are grateful to members of the MCCRC team and to attendees at the 4th Annual MCCRC Symposium (September 2017) for helpful comments and to Microsoft for the generous financial support that has made this project possible. We also acknowledge the financial support of the UK Engineering and Physical Sciences Research Council (EPSRC). Responsibility for views expressed, however, remains with the authors.

[*] Professor Emerita of Distributed Systems, Department of Computer Science and Technology, University of Cambridge.

[**] Researcher, Cloud Legal Project and Microsoft Cloud Computing Research Centre, both at the Centre for Commercial Law Studies, Queen Mary University of London.

[***] Professor of Privacy and Information Law and Project Leader, Cloud Legal Project, Centre for Commercial Law Studies, Queen Mary University of London and Senior Counsel, Bristows LLP. Joint Director of the Microsoft Cloud Computing Research Centre.

[****] Senior Research Fellow, Department of Computer Science and Technology, University of Cambridge.

ABSTRACT

This paper provides an introduction to blockchain technology and its legal implications. The paper consists of two parts. The first part looks at the technology behind the hype. It explains how blockchain technology works and can be deployed in various ways to create applications with different features, including open, distributed and closed, and centralised platforms. The second part analyses the technology's implications for several areas of law that will be relevant to companies and other organisations that seek to use blockchain technology, namely: contract law, data protection law, securities law, property law, intellectual property, and company law. The purpose of this paper is to help legal and other professional advisors understand blockchain technology and to alert users of blockchain technology to the current legal uncertainty and associated risks.

TABLE OF CONTENTS

I. INTRODUCTION 4
1.1 Blockchain Technology 5
1.2 Legal Analysis 8
II. THE TECHNOLOGY BEHIND THE HYPE 9
2. Core Components 9
2.1 Data Integrity 9
2.2 Identity Authentication 13
2.3 Summary 16
3. Trust and Control 16
3.1 Trustless Environments and Open, Distributed Platforms 18
3.2 Trusted Parties and Closed, Centralised Platforms 28
3.3 Governance and Control 33
4. Visibility and Identity 41
4.1 Visibility of the Record: Public and Private Platforms 41
4.2 Identity of Participants 43
5. Smart Contracts 45
III. BLOCKCHAIN AND THE LAW 49
6. Legal Analysis 49
6.1 Smart Contracts and Contract Law 50
6.2 Blockchain Data and the GDPR 58
6.3 Initial Coin Offerings and Securities Law 78
6.4 Digital Tokens and Property Law 84
6.5 Blockchain Databases and Intellectual Property Law 95
6.6 Digital Autonomous Organisations and Company Law 99
IV. CONCLUSIONS 101
7.1 Blockchain Technology 101
7.2 Blockchain and the Law 104

I. INTRODUCTION

[1] Excitement about blockchain and related technologies is soaring to new heights. The value of the two main cryptocurrencies, Bitcoin and Ethereum, has proved volatile with Bitcoin's price increasing twentyfold, from U.S. $1,000 in January 2017 to almost U.S. $20,000 in December 2017, before plummeting to around U.S. $9,000 as of March 2018.[1] Initial Coin Offerings (ICOs) raised an estimated U.S. $5.5 billion in 2017.[2] Organisations ranging from banks to charities publicly expressed their interest in using blockchain technology.[3] This flurry of activity sparked responses by legislators and regulators, including securities regulators in the United States and the EU.[4]

[1] *See Bitcoin (USD) Price*, COINDESK, https://www.coindesk.com/price/ (last visited Oct. 5, 2018) (change the date range in the chart to reflect January 1, 2017 as the start date and March 31, 2018 as the end date).

[2] *See* Ben McLannahan, *SEC Cyber Unit Eyes Initial Coin Offerings with Suspicion*, FIN. TIMES (Mar. 15, 2018), https://www.ft.com/content/b797e1ac-1b04-11e8-aaca-4574d7dabfb6 [https://perma.cc/7C94-XLSG].

[3] *See, e.g.*, Due.com, *Are Banks Ready to Embrace Blockchain Technology?*, NASDAQ (June 5, 2017, 10:00:43 AM EDT), https://www.nasdaq.com/article/are-banks-ready-to-embrace-blockchain-technology-cm798599 [http://perma.cc/75B4-EV6J]; Paul Lamb, *Transforming the Social Sector: Bitcoin and Blockchain for Good*, HUFFPOST, https://www.huffingtonpost.com/entry/transforming-the-social-sector-bitcoin-and-blockchain_us_59c169e3e4b0f96732cbc9c7 [https://perma.cc/9FW5-TP7S] (last updated Jan. 8, 2018).

[4] *See* McLannahan, *supra* note 2; *see also ESMA Highlights ICO Risks for Investors and Firms*, EUR. SEC. & MKTS. AUTHORITY (Nov. 13, 2017), https://www.esma.europa.eu/press-news/esma-news/esma-highlights-ico-risks-investors-and-firms [https://perma.cc/49K7-6PM].

[2] There are many tutorials and reports, and various books on blockchain.[5] However, a lot of the existing material assumes that readers are familiar with the underpinning technologies. Further, some sources fail to distinguish between the core components of blockchain technology, and the various ways in which the technology can be applied. Finally, the terminology used to describe blockchain is often unclear or inconsistent. As a result, many discussions of blockchain are marred by misunderstandings and can leave audiences mystified.

[3] This paper aims to demystify blockchain for a non-expert audience. It consists of two parts. The first part is an introduction to blockchain technology. The second part explores blockchain's legal implications. It argues that understanding the different ways in which platforms can apply blockchain technology is often key to accurate legal analysis. As a result, there can be no one-size-fits-all legal response. Instead, this paper aims to help legislators, regulators, and lawyers understand blockchain technology, so they can tailor appropriate legal solutions to each use case. Moreover, the initial exploration of legal implications could help those considering the use of a blockchain solution in almost any context.

1.1 Blockchain Technology

[4] In our view, a blockchain is a type of database: a structured collection of information. In this paper, we use the term *blockchain* to refer to a specific type of database that uses certain cryptographic functions to achieve the requirements of data integrity and identity

[5] *See, e.g.*, ANDREAS M. ANTONOPOULOS, MASTERING BITCOIN: UNLOCKING DIGITAL CRYPTOCURRENCIES (1st. ed 2014); ARVIND NARAYANAN ET AL., BITCOIN AND CRYPTOCURRENCY TECHNOLOGIES: A COMPREHENSIVE INTRODUCTION (Princeton Univ. Press eds., 2016); ROGER WATTENHOFER, THE SCIENCE OF BLOCKCHAIN (Inverted Forest Publishing eds., 2016).

authentication, as set out in the table below. Since blockchains commonly track transactions, they are often referred to as *ledgers*.[6]

Table 1. Two Key Requirements of Blockchain Technology

No.	Requirement	Component	Purpose
1.	Data integrity	Hash functions	To create a persistent, tamper-evident record of relevant transactions.
2.	Identity authentication	Public key infrastructure	To authenticate the party or parties associated with each transaction.

[5] In Section 2, below, we explain how hash functions can be used to create a persistent, tamper-evident record of transactions.[7] Then, we show how public key infrastructure (PKI) can authenticate the identity of the parties associated with those transactions.[8]

[6] We use the term distributed ledger technology (DLT) to refer to a ledger that is stored in a distributed manner across a peer-to-peer network. By this definition, a distributed ledger (DL) is also a blockchain if it uses a blockchain data structure to record transactions. However, a blockchain that is stored in a centralised manner is not a DL because it is not distributed.

[7] Cryptocurrencies, like Bitcoin and Ethereum, are the most well-known applications of blockchain technology and have shaped the public

[6] *See* NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY, DRAFT NISTIR 8202 BLOCKCHAIN TECHNOLOGY OVERVIEW (2018), at 15 [hereinafter NISTIR OVERVIEW].

[7] *See* discussion *infra* Section 2.1.

[8] *See* discussion *infra* Section 2.2.

perception of what *blockchain* is.[9] However, the Bitcoin and Ethereum platforms were configured to meet specific requirements for creating a digital currency that anyone can access known as *open* or *permissionless* systems.[10] They were intended to enable a so-called *trustless environment*, meaning the participants to a transaction need not trust each other.[11] These requirements shaped the ways in which early platforms applied blockchain technology, including with regard to public visibility and user pseudonimity.[12] Blockchains can be applied in a variety of ways to create platforms with different properties and features.[13] As blockchain technology is adopted for purposes other than currencies, the early requirements may not necessarily be carried forward. For instance, some applications entail *closed* or *permissioned* systems where participation is limited to a certain group of approved users.[14] In such cases, there is likely to be a higher level of trust among users, reducing the need for distributed storage and consensus protocols.[15]

---

[9] *See* David Hollerith, *Survey Polls American Awareness of Cryptocurrencies and ICOs*, BITCOIN MAG. (Nov. 6, 2017, 2:53 PM EST), https://bitcoinmagazine.com/articles/survey-polls-american-awareness-cryptocurrencies-and-icos/ [https://perma.cc/SAG2-QKCM].

[10] *See* NISTIR OVERVIEW, *supra* note 6, at 38.

[11] *See id.* at 45.

[12] *See* Jean Bacon, Johan David Michels, Christopher Millard, & Jatinder Singh, *Blockchain Demystified* 5 (Queen Mary University of London, School of Law Legal Studies Research Paper, No. 268/2017, 2017), https://ssrn.com/abstract=3091218 [https://perma.cc/5(U6-9F65] (citing the requirements of early cryptocurrencies); Daniel Genkin, Dimitrios Papadopoulos, & Charalampos Papmanthou, *Privacy in Decentralized Cryptocurrencies*, 61 COMM. ACM, June 2018, at 78, 78, https://cacm.acm.org/magazines/2018/6/228028-privacy-in-decentralized-cryptocurrencies/fulltext [https://perma.cc/7D4M-DTYS] (discussing user pseudonymity).

[13] *See* NISTIR OVERVIEW, *supra* note 6, at 40–44.

[14] *See id.* at 36.

[15] *See* discussion *infra* Section 3.2.

[8] In Sections 3 and 4, we explain how early platforms have applied blockchain technology in open, permissionless ways to create distributed ledgers. We then turn to closed, permissioned platforms and consider how these might differ in terms of their configuration and features, including centralised ledgers. Section 3 looks at the key issue of control over the blockchain. Section 4 considers the visibility of the blockchain record and user identity. Section 5 briefly outlines the role of smart contracts.

1.2 Legal Analysis

[9] Part Two explores blockchain technology's legal implications. In Section 6, we consider the legal implications of smart contracts, digital autonomous organisations, initial coin offerings, and digital tokens under contract law, data protection law, securities law, property law, intellectual property, and company law. In each area, we focus on legal issues raised by blockchain technology, as opposed to how blockchain technology can be used to improve compliance with legal requirements.

[10] We conclude that any particular blockchain-based platform may be more or less decentralised and more or less anonymous, based on application requirements and associated technical design decisions. These features in turn have significant legal implications, for instance with regard to the difficulty of reversing past transactions. This paper does not explore how blockchain transactions relate to real-world assets. While early applications tracked on-chain assets (i.e. digital tokens which exist only by virtue of the blockchain), some future applications will use tokens to reflect off-chain assets, including physical items, raising further legal complications.[16]

[16] *See* Chris Reed, Umamahesh Sathyanarayan, Shuhui Ruan, & Justine Collins, *Beyond BitCoin—Legal Impurities and Off-chain Assets*, 5–6 (Queen Mary University of London, School of Law Legal Studies Research Paper, No. 260/2017, 2017), https://ssrn.com/abstract=3058945 [https://perma.cc/C7EM-L4WL].

II. THE TECHNOLOGY BEHIND THE HYPE

2. Core Components

2.1 Data Integrity

[11] Blockchain technology aims to create a persistent, tamper-evident record of relevant transactions.[17] This section shows how hash functions can be used to create a tamper-evident data structure.

2.1.1 Hash Values Prove the Integrity of Data

[12] Hashing involves putting a data item (e.g. the contents of a document) through a *hash function*.[18] This function creates a string of digits of a fixed length that are unique to the input data item.[19] The output is called a *hash value*.[20] It is practically *impossible* for two different data items to hash to the same value (i.e. the probability of that occurring is extremely low). [21]

[13] As a result, hashing can be used to prove the integrity of the input data.[22] If the original input is changed in any way—even by a single

[17] *See* NISTIR OVERVIEW, *supra* note 6, at 1–2.

[18] *See* DONALD E. KNUTH, THE ART OF COMPUTER PROGRAMMING (Addison Wesley Longman eds., 2d ed. 1998).

[19] *See id.*

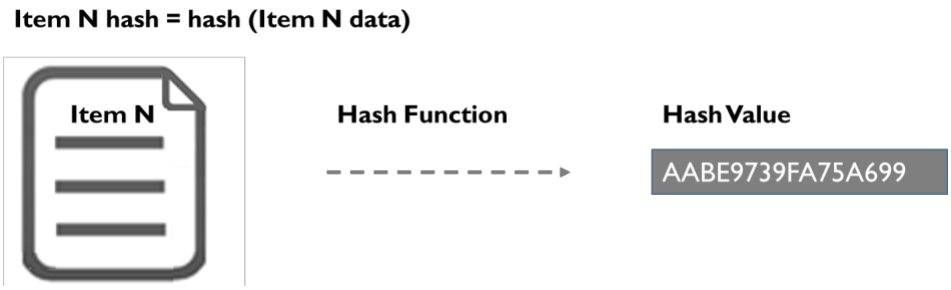
[20] *See id.*

[21] *See* Mohammad Peyravian et al., *On Probabilities of Hash Value Matches*, 17 COMPUTERS & SEC., 171, 171–73 (1998), http://www.mathcs.emory.edu/~whalen/Hash/Hash_Articles/On%20probabilities%20of%20hash%20value%20matches.pdf [https://perma.cc/M23H-X6JA].

[22] *See Ensuring Data Integrity with Hash Codes*, MICROSOFT (Mar. 29, 2017), https://docs.microsoft.com/en-us/dotnet/standard/security/ensuring-data-integrity-with-hash-codes [https://perma.cc/ZJC9-JUSJ].

character or space—the function will produce a totally unrelated hash value.[23] To prevent tampering, this requires the hash value—but not the data item itself—to be visible to external observers. If the hash value is unchanged, observers can be confident that the input data has not been tampered with.[24]

Figure 1: A Hash Function That Outputs a 16-digit (8 byte, 64 bit) Hash Value



[14] Hashing is *one-way*, in that it is not possible to recreate the original input from the hash value that the hash function outputs.[25] Hashing does not change or otherwise affect the input data item.[26] Unencrypted data, with the associated hash value, are readable by anyone with access to them.[27] In sum, the combination of a data item and its hash value is

[23] *See* NARAYANAN, *supra* note 5, at 12–15.

[24] *See* Kyriacos Pavlou & Richard T. Snodgrass, *Forensic Analysis of Database Tampering*, 33 ACM TRANSACTIONS ON DATABASE SYS. 109, 110 (2008), https://www2.cs.arizona.edu/~rts/pubs/SIGMOD06.pdf [https://perma.cc/W552-TEJF].

[25] *See* NISTIR OVERVIEW, *supra* note 6, at 12–13; *see* KNUTH, *supra* note 18.

[26] *See* BRUCE SCHNEIER, APPLIED CRYPTOGRAPHY: PROTOCOLS, ALGORITHMS AND SOURCE CODE IN C, § 2.4 (John Wiley et al. eds., 20th Anniversary ed., 2015) [hereinafter APPLIED CRYTOGRAPHY] (discussing how the hash function merely takes an image of the input data and converts that image into a hash value).

[27] *See id.* §§ 8.4, 18.12.

tamper-evident, in that it would be evident to any observer if the data item were changed in any way.[28]

2.1.2 Hash Pointers Create Tamper-Evident Data Chains

[15] Hash values can also be used to make a data structure of multiple data items tamper-evident, through *hash pointers*.[29] Hash pointers prove the integrity of a string of data items, including both their contents and their sequence.[30]

[16] Hash pointers achieve this by linking a series of items together, as illustrated in Figure 2 below for Items 6–8.[31] The data of each item is combined with the hash value of the previous item and put into a hash function.[32] This generates that item's hash value, which is then included in the next item.[33] For example, the hash value of Item 8 is based on both Data 8 and the hash of Item 7. Item 7 contains Data 7 and the hash of Item 6, and so on, back to the start of the chain.

[28] *See id.* § 8.4 (arguing that it is very difficult to tamper with and substitute keys without another person noticing); *see also* NISTIR OVERVIEW, *supra* note 6, at 52 (describing a tamperproof hash chain).

[29] *See* NISTIR OVERVIEW, *supra* note 6, at 19–23.

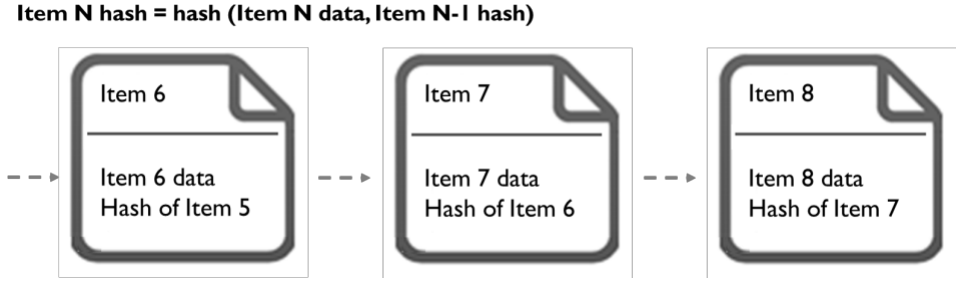
[30] *See id.*

[31] *See id.*

[32] *See id.*

[33] *See id.*

Figure 2. A Tamper-evident Chain of Items Using Hash Pointers



[17] This results in a tamper-evident data chain. The data of Item 7 cannot be changed without changing its hash value. Any attempt to change the values of Item 7 and *re-hash* it would break the link between the items, since the hash of Item 7 is recorded in Item 8. Provided an external observer can view the hash pointers, they can spot any tampering. So, if a (fraudulent) change were to be made in the data of Item 7, all subsequent blocks in the chain would have to be re-hashed to rebuild the chain.

2.1.3 Blockchains Group Transactions into 'Blocks' in a 'Chain'

[18] Blockchains record large numbers of transactions.[34] For efficiency reasons, they achieve this by grouping individual transaction records together into a block, and chaining blocks together using hash pointers, instead of merely linking single data items.[35]

[19] A block consists of two parts. The *block body* contains the transactions that the block records.[36] The *block header* includes the hash

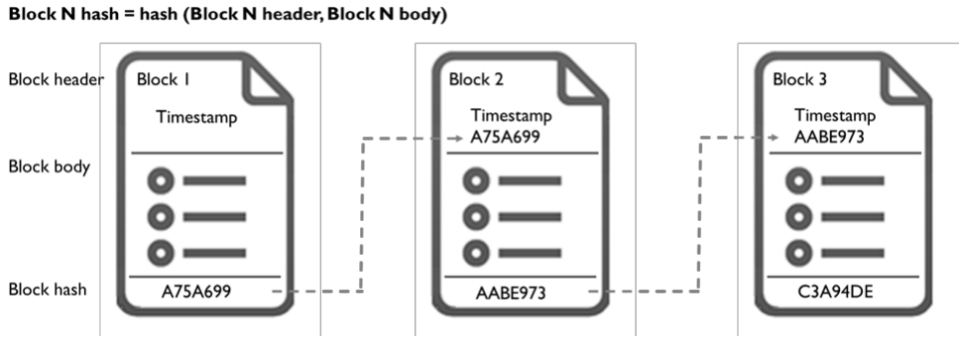
[34] *See* Satoshi Nakamoto, *Bitcoin: A Peer-to-Peer Electronic Cash System*, at 2, https://bitcoin.org/bitcoin.pdf [https://perma.cc/Y9QJ-UD9A] (explaining the process of how transactions are verified by a chain of ownership).

[35] *See* NISTIR OVERVIEW, *supra* note 6, at 23.

[36] *See id.* at 19–23; *see also* Minhaj Ahmad Khan & Khaled Salah, *IoT Security: Review, Blockchain Solutions, and Open Challenges*, 82 FUTURE GENERATION COMPUTER SYS. 395, 405 (2018).

of the previous block and some metadata such as a timestamp.[37] Blocks are hashed as a whole, i.e. the header and the body are used as input data for the hash function.[38] Thus, a block's hash value is created from data that includes the hash of the previous block.[39] Blocks are chained using these block hash pointers, creating a *blockchain*, as shown in Figure 3.[40]

Figure 3. A Simple Blockchain Representation Showing Three Chained Blocks



In practice, for scalability and to limit access latency, a more general 'Merkle Tree' structure is used to record the transactions within each block.[41]

2.2 Identity Authentication

[20] To record a transaction or other data item securely, blockchain technology needs to authenticate the relevant parties, before storing it in a

[37] *See id.*

[38] *See id.*

[39] *See id.*

[40] *See id.* Figure 3 does not represent any particular platform's block header in detail and is intended as an example.

[41] *See* Nakamoto, *supra* note 34, at 4.

tamper-evident database.[42] Otherwise, an attacker could simply pose as another party and propose new transactions, such as sending another user's Bitcoins to an address they control. This section explains how blockchain technology uses public key infrastructure to authenticate users' identities and ward off such attacks.

[21] Public key infrastructure (PKI) allows users to generate a key pair consisting of a public and a private key to sign a data item, and to validate whether a digital signature is correct.[43] Data encrypted with the public key can only be decrypted using the private key and vice versa.[44] If a certain set of data can be decrypted with the public key, this proves the data was encrypted by, and therefore came from, the holder of the private key.[45]

[22] As the names imply, users must never reveal their private keys, since anyone who knows a private key can masquerade as its owner.[46] Private keys should not be transmitted, even when encrypted.[47] Conversely, the public key is published to represent the individual or

[42] *See* Steve Olshansky et al., *Do Blockchains Have Anything to Offer Identity*, INTERNET SOC'Y (Mar. 7, 2018), https://www.internetsociety.org/resources/doc/2018/blockchain-identity/ [https://perma.cc/CZQ4-N5KH].

[43] *See* NISTIR OVERIEW, *supra* note 6, at 13–14; *see Public Key Infrastructure*, MICROSOFT (May 30, 2018), https://docs.microsoft.com/en-us/windows/desktop/seccertenroll/public-key-infrastructure [https://perma.cc/DMU7-SDVZ].

[44] *See* SCHNEIER, *supra* note 26, § 2.7 (illustrating how two users can send and verify encrypted messages).

[45] *See id.*

[46] *See* NISTIR OVERVIEW, *supra* note 6, at 46.

[47] *See Public Key Cryptography*, IBM KNOWLEDGE CENTER, https://www.ibm.com/support/knowledgecenter/en/SSMKHH_9.0.0/com.ibm.etools.mft.doc/ac55940_.htm [https://perma.cc/DJG4-3HGP] (noting that the sharing of "secret keys makes them vulnerable to theft").

entity holding the corresponding private key.[48] PKI can be used to create digital signatures, which establish that a transaction emanated from a certain user.[49] To sign a data item, the sender encrypts the data with their private key.[50] If the public key can be used to decrypt the data, this proves that the sender held the private key.[51]

[23] With blockchain, the private key is used to encrypt the transaction record.[52] This effectively establishes that the transaction originated with the associated party. Either the owner of the corresponding private key must have signed the data, or the key has been compromised by theft or sharing. Transaction records are signed before being included in blocks.[53]

[24] Each party's private key is their means of access to the blockchain platform.[54] If they lose their private key, the platform can no longer authenticate their identity and will deny them access.[55] Thus, if a user loses their Bitcoin private key, they can no longer access any associated coins.

[48] *See id*. (noting that the public key is distributed so that users may encrypt messages to the person holding the corresponding private key).

[49] *See* NISTIR OVERVIEW, *supra* note 6, at 46.

[50] *See id.* at 13–15.

[51] *See id.*

[52] *See id.*

[53] *See id.*

[54] *See* NISTIR OVERVIEW, *supra* note 6, at 14–15.

[55] *See* Matthew Sparkes, *The £625m Lost Forever—The Phenomenon of Disappearing Bitcoins*, TELEGRAPH, (Jan. 23, 2015, 7:00 AM), https://www.telegraph.co.uk/technology/news/11362827/The-625m-lost-forever-the-phenomenon-of-disappearing-Bitcoins.html [https://perma.cc/D2F7-WEJD].

2.3 Summary

[25] In sum, hash functions can be used to generate hash pointers that link blocks of transactions together in a chain. The hash pointers establish the integrity of the data within each block, as well as the order of the blocks, thereby creating a tamper-evident data structure. For example, Bitcoin generates hash pointers using Secure Hash Algorithm 256 (SHA-256), a well-known hash function that generates a 256-bit (or 32-byte) hash.[56]

[26] A private key can be used to establish an individual's identity through a digital signature.[57] Blockchains combine private keys and hash functions to create a long-term, tamper-evident record of transactions between parties with verified identities.[58] However, the intended long-term storage of blockchain records raises the issue of whether current encryption schemes will continue to be sufficient. Quantum computing may present a challenge to encryption in the long term.

3. Trust and Control

[27] This section covers a key question for each application of blockchain technology, namely: who will control the blockchain? This can be split into three sub-questions: (i) who stores a copy of the current version of the blockchain; (ii) who can add new blocks to it, and (iii) who controls how the system works?

[28] As set out above, the use of a blockchain should give users confidence in a tamper-evident ledger of their transactions. Further, users should be confident that nobody can transfer their assets without access to their private key. However, using a blockchain does not in itself prevent

[56] *See* ANTONOPOULOS, *supra* note 5, at ch. 7.

[57] *See* NISTIR OVERVIEW, *supra* note 6, at 14, 46.

[58] *See id.*

tampering by whoever controls the ledger.[59] For example, an ill-intentioned record-keeper could potentially change transactions in past blocks and then re-hash all the blocks up to the present block, so that the new hash pointers link the blocks. Thus, in a system where visibility and control over the ledger are centralised in the hands of a single party, users need to trust this party not to tamper with the ledger.

[29] Early cryptocurrencies seek to provide a trustless environment.[60] Instead of centralising control, they allow anyone to store a local copy of the blockchain and propose new blocks for inclusion.[61] To achieve this, they rely on a network of *nodes* to store copies across a peer-to-peer network and *miners* to propose new blocks, as explained in Section 3.1 below.[62] We use Bitcoin as an example to illustrate the workings of an open, distributed platform.

[30] In contrast, future applications of the technology may operate in environments where there is a degree of trust. As a result, future platforms may feature either a single entity, known as a 'Trusted Third Party' or TTP, or a small group of participants that operate the blockchain. Section 3.2 considers how future, centralised platforms may differ from early cryptocurrencies. Finally, Section 3.3 covers issues of blockchain governance and control, including changes to the software and the possibility of reversing past transactions.

[59] *See id.* at 36–37.

[60] *See* Nakamoto, *supra* note 34, at 1–2 (describing a system in which two parties can transact directly without a trusted third party using a distributed, time-stamped system).

[61] *See id.* at 3.

[62] *See* discussion *infra* Section 3.1.

3.1 Trustless Environments and Open, Distributed Platforms

3.1.1 Users: Permissionless Access

[31] Early cryptocurrency platforms involve three overlapping groups: users, nodes, and miners.[63] Users participate in the platform by buying and selling coins like Bitcoin or Ether. To participate, they run open source code on their local hardware.[64] This software broadcasts the users' required transactions onto the network, to be incorporated into blocks by miners.[65] In Bitcoin, the pool of transactions waiting to be confirmed is called the *mempool*.[66]

[32] In terms of access, early cryptocurrencies are open or permissionless at the user level.[67] For example, in Bitcoin, anybody can generate a public private key pair and a Bitcoin address via their open source software.[68] Alternatively, they can join a software wallet service online that generates the key pair for them.[69] To start trading, users can

[63] *See* NISTIR OVERVIEW, *supra* note 6, at 15–25.

[64] *See How Do Bitcoin Transactions Work?*, COINDESK (Jan. 29, 2018), https://www.coindesk.com/information/how-do-bitcoin-transactions-work/ [https://perma.cc/CC8Q-VH2U].

[65] *See id.*

[66] *See, e.g.*, *Mempool Size*, BLOCKCHAIN.COM, https://blockchain.info/charts/mempool-size [https://perma.cc/3BF3-BTBM].

[67] *See* NISTIR OVERVIEW, *supra* note 6, at 38–40.

[68] *See id.* at 14; Noelle Acheson, *How to Store Your Bitcoin*, COINDESK (Jan. 20, 2018), https://www.coindesk.com/information/how-to-store-your-bitcoins/ [https://perma.cc/ZKH3-7D89] [hereinafter Acheson, *How to Store Bitcoin*] (noting that free software can be used to install a wallet, and how the original software wallet was Bitcoin Core).

[69] *See, e.g.*, COINBASE.COM, https://wallet.coinbase.com [https://perma.cc/H8Y5-BDBY]; BLOCKCHAIN.COM, https://login.blockchain.com/#/signup (last visited Sept. 15, 2018) (allowing users to join an online wallet service).

buy Bitcoin from online exchanges, or by finding other users to trade Bitcoin in person.[70] However, using intermediary services such as wallets or exchanges requires a level of trust from participants, since they store copies of the user's private key.[71] While the Bitcoin system itself has not been hacked, several exchanges have been, resulting in substantial losses.[72]

3.1.2 Nodes: Storage and Validation

[33] Nodes store a local copy of the blockchain.[73] *Full* nodes store a copy of the entire blockchain, while *light* nodes hold only a subset of the blockchain in order to verify transactions.[74] The early applications of blockchain technology are also *open* or *permissionless* at the node level. Anybody can become a node by downloading and running the relevant software and storing the blockchain archive.[75] In practice, only a subset of users will do so, since this requires significant bandwidth and storage space.[76] As of March 2018, running a full node requires 145GB of free

[70] *See generally* LOCALBITCOINS.COM, https://localbitcoins.com [https://perma.cc/KVH8-X7ZL] (providing users an online form to buy and sell Bitcoin).

[71] *See* Kevin D. Werbach, *Trust, But Verify: Why the Blockchain Needs the Law*, BERKELEY TECH. L.J. (forthcoming 2018) (manuscript at 27), https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2844409 [https://perma.cc/2DUM-KHMZ] (comparing the trust users extend to wallet service providers storing their private cryptographic keys to the trust a consumer extends to a bank).

[72] *See id.* at manuscript 27–28 (describing several incidents of hacking).

[73] *See* NISTIR OVERVIEW, *supra* note 6, at 23–24.

[74] *See id.* (describing the differences between *full* and *light* node).

[75] *See id.* at 36–40.

[76] *See Running a Full Node*, BITCOINCORE, https://bitcoin.org/en/full-node#what-is-a-full-node [https://perma.cc/MK3J-6S8G].

disk space.[77] There were over 10,000 nodes running on the Bitcoin core network as of March 2018.[78]

[34] Nodes discover and maintain connections with other nodes across a P2P network.[79] When they receive a new block from another node on the network, they check that it is valid.[80] This includes a check to prevent users spending the same coin twice, known as double-spending.[81] They do so by checking the proposed transaction against a list of previous, unspent transaction outputs, known as the UTXO database.[82] If the block is valid, the node adds it to their local copy of the blockchain and broadcasts it to other nodes on the network.[83]

3.1.3 Miners: Distributed Control Over New Blocks

[35] Miners assemble transactions into blocks and broadcast those blocks to nodes across the P2P network, so the nodes can append the new block to their local copies[84] Miners are rewarded for adding new blocks

[77] *See id.*

[78] *See Bitcoin Core Nodes (historical)*, COIN DANCE, https://coin.dance/nodes [https://perma.cc/25TM-WRFL].

[79] *See* NISTIR OVERVIEW, *supra* note 6, at 23–25.

[80] *See id.* at 26–29.

[81] *Double Spend*, BITCOIN, https://bitcoin.org/en/glossary/double-spend [https://perma.cc/R476-L6RX].

[82] *See* Gavin Andresen, *UTXO uh-oh…*, SVBTLE BLOG (May 8, 2015), http://gavinandresen.ninja/utxo-uhoh [https://perma.cc/XN8Y-SNMK] A transaction output is the result of a transaction, transferring an amount of coin that is not yet spent to a new address. The transaction giving ownership to the payer is removed from the UTXO and the transaction giving the currency to the payee is added to the UTXO. All inputs to a transaction must be in this database for the transaction to be valid.

[83] *See* NISTIR OVERVIEW, *supra* note 6, at 23–25.

[84] *See id.* at 26–28.

with newly minted crypto-coins, as well as any transaction fees users have offered.[85] Bitcoin and Ethereum are open or permissionless at the miner level.[86] Any user can become a miner by running mining software on their local machine.[87] Thus, these early applications were designed to be open or permissionless on three levels, as set out in the table below.

Table 2. Bitcoin: An Open/Permissionless Application of Blockchain Technology

No.	Group	Function	Permission
i.	Users	Propose new transactions	Open: Anyone can join the network and send and receive Bitcoin.
ii.	Nodes	Store copies of the DL	Open: Anyone can download the software and run a Bitcoin node.
iii.	Miners	Propose new blocks	Open: Anyone can mine new blocks and broadcast them to the P2P network

3.1.4 Distributed Storage and Consensus Protocols

[36] Allowing anyone to operate a node means the blockchain can be stored in a distributed manner, i.e. as a Distributed Ledger or DL.[88] Storing a blockchain in such a way has three main advantages. First, it protects data from tampering by any single centralised party.[89] Second, a DL may be less vulnerable to attack since there is no single *master copy* of

[85] When a user signs a Bitcoin transaction, they can offer *transaction fees* in return for priority processing of their transactions. *See* Nakamoto*, supra* note 34, at 4.

[86] *See* NISTIR OVERVIEW, *supra* note 6, at 26–28.

[87] *See id.*

[88] *See id.* at 38.

[89] *See id.* at 36.

the ledger to target.[90] An attacker would instead have to make changes to a number of copies across the network. Finally, a DL is resilient, since there is no single point of failure to target with a denial of service (DoS) attack.[91] Even if several nodes failed, the network would still continue to function.

[37] However, the major challenge for a DL is ensuring that all of the nodes hold a consistent and up-to-date copy of the blockchain and that participant/system behaviour is valid and appropriate.[92] In blockchain terms, the nodes must achieve *consensus*.[93] *Full nodes* start by downloading the latest version of the ledger.[94] Thus, to achieve consensus, the system needs to ensure that each node adds the same new blocks to their local copy.[95] To this end, all nodes must follow the same rules for deciding when to add a new block.[96] These rules are called a consensus protocol, which is embedded in the software each node runs.[97] In an open, permissionless application, there may be thousands of widely distributed nodes holding copies. Therefore, these distributed consensus protocols cannot agree on new blocks one block at a time, as in conventional

[90] *See* Olivier Boireau, *Securing the Blockchain Against Hackers*, 2018 NETWORK SECURITY 8, 8–10 (2018).

[91] *See* NISTIR OVERVIEW, *supra* note 6, at 9.

[92] *See id.* at 26.

[93] *See* Nakamoto, *supra* note 34, at 8 (noting that nodes "vote with their CPU power" to accept and validate new blocks).

[94] *See* NISTIR OVERVIEW, *supra* note 6, at 23–24.

[95] *See id.*

[96] *See id.*

[97] *See id.* at 26.

consensus protocols.[98] Instead, they build up chains of blocks as they receive them.

[38] In order for nodes to accept their blocks, miners need to generate new blocks that accord with the consensus protocol.[99] Since anyone can join as a miner or node, the platform needs safeguards against malicious actors who try to take control of the ledger. If starting nodes and mining new blocks were costless, an attacker could flood the system with new nodes and newly mined blocks, in what is known as a *Sybil* attack.[100] To defend against this, early cryptocurrencies make mining new blocks costly, by requiring *proof of work*.[101]

i. Proof of Work

[39] The consensus protocol of Bitcoin and Ethereum requires miners to demonstrate proof of work (PoW) for each new block.[102] To do so, each miner must find the answer to a computationally difficult *puzzle*.[103] Solving the puzzle can be seen as a demonstration of good faith, since it requires the miner to invest resources, CPU power and electricity, into

[98] *See, e.g.*, Marko Vukolic, *The Quest for Scalable Blockchain Fabric: Proof-of-Work vs. BFT Replication*, 9591 LECTURE NOTES COMPUTER SCI. 112 (2016) (discussing consensus protocols used by Bitcoin).

[99] *See* NISTIR OVERVIEW, *supra* note 6, at 26.

[100] *See* John Douceur, *The Sybil Attack*, *in* PEER-TO-PEER SYSTEMS 251, 252 (Peter Druschel et al. eds., 2002); *see also* Vukolic *supra* note 98, at 113.

[101] *See* Nakamoto, *supra* note 34, at 3.

[102] *See* NISTIR OVERVIEW, *supra* note 6, at 26–28.

[103] *See id.*

updating the ledger.[104] Nodes will only accept blocks that contain the solution to the puzzle.[105]

[40] The puzzle works using hash functions.[106] As set out in Section 0, the header and body of a block are run through a hash function to generate that block's hash value.[107] To mine a valid new Bitcoin block, the hash value of that block must achieve a particular pattern, namely it must start with a certain number of zeros.[108] To create a valid block, a miner must add a random number, known as a *nonce*, to the header of the block such that the resulting hash value fits the pattern.[109] Miners solve this puzzle by trial-and-error, iterating through different nonces until the hash value has the required number of leading zeros.[110] The higher the number of zeros required, the harder the puzzle.

[41] The more computational resources—CPU power— a miner devotes to solving the problem, the more likely they will solve it first.[111] In practice, professional miners use dedicated hardware, known as Application Specific Integrated Circuits (ASICs), and base themselves

[104] *See id.*

[105] *See id.*

[106] *See id.*

[107] *See* discussion *supra* Section 2.1.3.

[108] *See* Nakamoto, *supra* note 34, at 3.

[109] *See* NISTIR OVERVIEW, *supra* note 6, at 27; *see also* Vitalik Buterin, *A Next Generation Smart Contract & Decentralized Application Platform*, ETHEREUM WHITE PAPER, 6–7, [hereinafter Buterin, ETHEREUM WHITE PAPER] http://blockchainlab.com/pdf/Ethereum_white_paper-a_next_generation_smart_contract_and_decentralized_application_platform-vitalik-buterin.pdf [https://perma.cc/VY99-CDUJ].

[110] *See* NISTIR OVERVIEW, *supra* note 6, at 27.

[111] *See id.* at 28.

near sources of cheap electricity to increase their efficiency in mining Bitcoin.[112]

[42] The puzzle is difficult to solve, but easy to verify.[113] This means that when a successful miner broadcasts a block with the solution to other nodes, they can easily check that the miner has solved it, by rehashing the block containing the miner's nonce.[114] The nodes then propagate the valid block across the peer-to-peer network.[115]

[43] The difficulty of the puzzle and the amount of computational resource devoted to solving it determine the frequency of new blocks.[116] The Bitcoin protocol dynamically adjusts the difficulty of the puzzle, to ensure that a new block is added every ten minutes, on average.[117]

[44] Although it enhances security, PoW uses large amounts of energy. All miners expend energy trying to solve the puzzle, but only one of the miners will successfully create a new block. Researchers have estimated that Bitcoin mining consumes 100–500 MW per day, or 3–16 PJ per year. This is similar to the yearly energy expenditure of c. 200,000-1.2m EU

[112] *See* Evelyn Cheng, *Bitcoin 'Mining' Goes from Enthusiasts to Giant Enterprises as Digital Currencies Surge*, CNBC (Aug. 1, 2017, 3:44 PM ET), https://www.cnbc.com/2017/08/01/bitcoin-mining-goes-from-enthusiasts-to-giant-enterprises.html [https://perma.cc/5Z6Q-TG9F].

[113] *See* NISTIR OVERVIEW, *supra* note 6, at 28.

[114] *See id.*

[115] *See id.*

[116] *See* Nakamoto, *supra* note 34, at 3.

[117] *See id.* at 3; *see also* Buterin, ETHEREUM WHITE PAPER, *supra* note 109, at 6 (achieving consensus).

households.[118] A single Bitcoin transaction requires an estimated 200kWh of energy, compared to around 0.01kWh per Visa transaction.[119] To reduce the costs of achieving consensus, Ethereum is considering moving to a consensus protocol that combines proof of stake and sharding, i.e. partitioning a large database into many smaller parts.[120]

ii. Attacking a PoW Blockchain

[45] As set out in Section 2.3 above, DLs have strong security mechanisms. For instance, regardless of how much hash power an attacker has, they cannot propose new transactions using another user's Bitcoins, since they do not have access to that user's private key.[121] Nor can they spend the same coin twice in new transactions, since nodes would not verify those payments.[122]

[46] Instead, to attack a DL that uses PoW, the attacker must gather more computational power than the rest of the network combined.[123] This is called a *51% attack*, since the attacker must control more than 51% of

[118] *See Average Electricity Consumption Per Electrified Household*, WORLD ENERGY COUNCIL, https://wec-indicators.enerdata.net/household-electricity-use.html#/primary-energy-intensity-ajusted-EU.html, [https://perma.cc/7B9Q-GPNQ] (last updated May, 2016).

[119] *See Why Bitcoin Transactions Are More Expensive Than You Think*, ING (Oct. 13, 2017), https://think.ing.com/opinions/why-bitcoin-transactions-are-more-expensive-than-you-think/ [https://perma.cc/XQ4E-L5YX].

[120] *See* Vitalik Buterin, *Ethereum 2.0 Mauve Paper* (Sept. 15, 2018), [hereinafter Buterin, *2.0 Mauve Paper*] https://cdn.hackaday.io/files/10879465447136/Mauve%20Paper%20Vitalik.pdf [https://perma.cc/Z86H-LDMH]; *see also* NISTIR OVERVIEW, *supra* note 6, at 29

[121] *See* Nakamoto, *supra* note 34, at 6.

[122] *See id.* at 8.

[123] *See id.* at 1.

the hashing power in the system.[124] The attacker would be likely to consistently solve PoW first and thus, control the addition of new blocks.[125]

[47] As a result, the attacker would not only consistently reap the mining rewards but could also reject blocks containing certain transactions in order to obtain benefit. In addition, an attacker controlling 51% of the hashing power could scam other users through a so-called *double-spending* attack.[126]

[48] A single attacker would have to spend significant resources in order to obtain 51% hashing power. However, in practice, many Bitcoin miners work together as part of large, centrally operated *mining pools*.[127] Since the PoW problem is easy to partition, miners in these pools try to solve the puzzle independently and in parallel, by working on separate parts of the possible solution, but agree to share any earnings from mining blocks with others in the pool.[128] These pools concentrate hashing power and could be used for a 51% attack.[129] In 2015, some of the largest Bitcoin mining pools voluntarily split into smaller pools because the top two pools

[124] *See* Buterin, ETHEREUM WHITE PAPER, *supra* note 109, at 8.

[125] *See* Ittay Eyal & Emin Gun Sirer, *Majority is Not Enough: Bitcoin Mining is Vulnerable*, CORNELL U. LIBR. (Nov. 15, 2013), https://arxiv.org/pdf/1311.0243.pdf [https://perma.cc/4LZ4-TEUD].

[126] *See id.*

[127] *See* NISTIR OVERVIEW, *supra* note 6, at 28

[128] *See* Rainer Böhme et al., *Bitcoin: Economics, Technology, and Governance*, 29 J. ECON. PERSP. 213, 222 (2015).

[129] *See* Primavera De Filippi & Benjamin Loveluck, *The Invisible Politics of Bitcoin: Governance Crisis of a Decentralised Infrastructure*, 5 INTERNET POL'Y REV. 1, 10–11 (2016).

held a majority of the CPU power.[130] As of March 2018, the largest Bitcoin mining pool (BTC.com) had 25% of the network's hash power.[131]

[49] That said, even if miners have the ability to engage in a 51% attack, they may not have the incentive to do so.[132] Miners have an economic interest in maintaining high Bitcoin prices.[133] They are paid in Bitcoin for their mining and many have invested in dedicated hardware to support the currency.[134] A successful attack on Bitcoin would reduce its value, thereby jeopardising their ability to generate returns on their investment.[135] Nonetheless, the system remains vulnerable to a politically motivated 51% attack, for instance from a government commandeering one or more of the big mining pools.[136]

3.2 Trusted Parties and Closed, Centralised Platforms

[50] Above, we have seen how early cryptocurrencies were designed to operate as open, permissionless platforms in trustless environments. As a result, they feature distributed storage and adding of new blocks managed

[130] *See* Larissa Lee, *New Kids on the Blockchain: How Bitcoin's New Technology Could Reinvent the Stock Market*, 12 HASTINGS BUS. L.J. 81, 107 (2016).

[131] *See Bitcoin Hashrate Distribution*, BLOCKCHAIN, https://blockchain.info/pools?timespan=24hrs [https://perma.cc/6WJ5-MGNX].

[132] *See* Nakamoto, *supra* note 34, at 4.

[133] *See* NISTIR OVERVIEW, *supra* note 6, at 44.

[134] *See* Angela Walch, *The Bitcoin Blockchain as Financial Market Infrastructure: A Consideration of Operational Risk*, 18 N.Y.U. J. LEGIS. & PUB. POL'Y 837, 861–63 (2015).

[135] *See id.*

[136] *See id.* at 863.

by complicated consensus protocols and resource-intensive mining to ensure that no single party controls the addition of new blocks.[137]

[51] However, blockchain-based platforms need not all operate in trustless environments.[138] Instead, they may avoid costly consensus protocols by re-introducing trusted intermediaries that control the blockchain by storing copies, i.e. acting as nodes, and determining which new blocks are added, i.e. acting as miners. Having fewer miners also allows less costly conventional one-block-at-a-time consensus protocols to be used. Such systems are closed or permissioned at the level of nodes or miners, since storage and mining is limited to certain parties.[139] The result is a more centralised platform compared to the open, distributed platforms discussed above.

[52] Such solutions require a level of trust from users, either in a single centralised trusted third party (TTP) or in a small number of trusted nodes.[140] Closed, permissioned systems can offer better transparency and safeguards as regards data integrity compared to traditional databases and may themselves inspire trust, since parties can limit participation to keep malicious actors off the platform.[141]

[53] In many instances, consumers may prove willing to trust reputable companies and citizens may trust government agencies with centralised

[137] *See generally* Nakamoto, *supra* note 34 (discussing the structure of Bitcoin).

[138] *See* Vitalik Buterin, *On Public and Private Blockchains*, ETHEREUM: BLOG (Aug. 6, 2017), [hereinafter Buterin, *Public and Private Blockchain*] https://blog.ethereum.org/2015/08/07/on-public-and-private-blockchains/ [https://perma.cc/38QR-GRBM].

[139] *See id.*

[140] *See id.*

[141] *See id.*

blockchain management.[142] After all, they currently trust many centralised record-keepers to maintain accurate records, without the use of blockchains. For example, users currently trust Twitter not to change their past tweets. If tweets were stored on a blockchain, they would be tamper-evident. However, Twitter did not need a blockchain to gain users' trust, since users understand that tampering with past tweets would damage the company's reputation. This gives it a strong incentive to refrain from doing so. Users may similarly prove willing to trust reputable operators of closed, permissioned blockchain platforms.

[54] In terms of access, such centralised blockchain models can be open, permissionless at the user level—meaning anyone can join—or be closed, permissioned systems, access to which is limited to certain users.[143] For instance, a centralised blockchain operator can limit access only to users who have been through a vetting process.[144] We look at two models for closed, permissioned systems below.

3.2.1 A Centralised TTP Model

[55] Governments are exploring the use of blockchain for large, centrally managed databases, such as land registers.[145] Provided citizens are willing to trust their government, such a blockchain need not be stored at multiple nodes across a P2P network. Instead, it could be stored centrally with a government agency, such as the land registry, acting as a

[142] *See* Izabella Kaminska, *Blockchain's Governance Paradox*, FIN. TIMES ALPHAVILLE (June 14, 2017, 5:50 PM), https://ftalphaville.ft.com/2017/06/14/2190149/blockchains-governance-paradox/ [https://perma.cc/5BFD-2TDG].

[143] *See* Buterin, *Public and Private Blockchain*, *supra* note 138.

[144] *See id.*

[145] *See, e.g.*, Stan Higgins, *UK Land Registry Plans to Test Blockchain in Digital Push*, COINDESK (May 12, 2017, 11:00 UTC), https://www.coindesk.com/uk-land-registry-plans-test-blockchain-digital-push/ [https://perma.cc/8RVU-QYN8].

TTP.[146] The blockchain is publicly visible; this would increase the transparency of the registry's record-keeping, without requiring distributed storage.

[56] Estonia is often considered a pioneer in the use of blockchain technology.[147] Since Estonian independence in 1991, citizens have been issued a proof of identity via a PKI-based identity card.[148] Since 2012, blockchain-like approaches have been used to assist in maintaining the integrity of data and transactions regarding national health, judicial, legislative, and other public services.[149] A small number of dedicated nodes are involved in agreeing on the blocks in the ledger, with a view to checking that the constituent system components are operating correctly.

[57] To bolster trust in a TTP-based system, archival copies of the DL could be stored at independent nodes, such as with an Ombudsman. Any tampering by the record-keeper would then be evident through comparison with the independently-stored copies. Users would still need to trust the TTP and independent archival nodes not to collude against their interests.

[146] *See* Buterin, *Public and Private Blockchain*, *supra* note 138.

[147] *See* Colin Adams, *Estonia, A Blockchain Model for Other Countries?*, INVEST IN BLOCKCHAIN (Jan. 4, 2018) http://www.investinblockchain.com/estonia-blockchain-model/ [https://perma.cc/P3ZQ-3LLQ].

[148] *See E-Identity*, E-ESTONIA (Mar. 20, 2018), https://e-estonia.com/solutions/e-identity/id-card/ [https://perma.cc/37RL-CWN4].

[149] *See Frequently Asked Questions: Estonian Blockchain Technology,* E-ESTONIA, https://e-estonia.com/wp-content/uploads/faq-a4-v02-blockchain.pdf [https://perma.cc/4D2X-XDA4].

Table 3: A 'Closed' or 'Permissioned' Blockchain Model with a TTP

No.	Group	Function	Permission
i.	Users	Propose new transactions	Closed: the TTP vets users before they can join, for instance to register land on the registry.[150]
ii.	Nodes	Store copies of the DL	Closed: the TTP acts as a single node, holding the master copy.
iii.	Miners	Propose new blocks	Closed: the TTP is the only party who updates the ledger.

3.2.2. A Trusted Nodes Model

[58] Commercial entities such as banks are also exploring ways to use blockchain to settle payments amongst themselves.[151] In such cases, multiple parties could set up a system with a defined number of *trusted nodes* who each store copies of the blockchain.[152] Since the number of trusted nodes is known, they could follow a less costly traditional, one-block-at-a-time consensus protocol, where nodes agree on each block to be added to the chain before continuing to the next block.[153]

[59] Such closed platforms restrict control over the blockchain by limiting permission to store the ledger and add new blocks to a small number of trusted parties.[154] The platform can limit permission in respect

[150] For example, the land registry may require users to prove their identity, for instance through a government-issued ID, before giving them access to the system. In practice, in some jurisdictions, users may need to interact with a land registry through a lawyer or notary.

[151] *See The R3 Story*, R3., http://www.r3.com/about/ [https://perma.cc/ZDK5-KMUJ].

[152] *See* Buterin, *Public and Private Blockchain*, *supra* note 138.

[153] *See* Bacon et al., *supra* note 12.

[154] *See* Buterin, *Public and Private Blockchain*, *supra* note 138.

of users, nodes, and miners, depending on the level of trust and desired functionality.[155] The table below shows a possible configuration.

Table 4: A 'Closed,' 'Permissioned' Blockchain Model with Trusted Nodes

No.	Group	Function	Permission
i.	Users	Propose new transactions	Closed: only authorised parties can join and participate.
ii.	Nodes	Store copies of the DL	Closed: only trusted nodes store copies of the ledger.
iii.	Miners	Propose new blocks	Closed: trusted nodes act as miners according to a consensus protocol.

[60] The result is a closed, permissioned platform with a *shared*—as opposed to distributed—ledger that should have lower running costs than distributed platforms, since there are fewer nodes. Moreover, the nodes may be able to process transactions more quickly, since transactions can be verified and blocks mined by a small number of trusted nodes, each with high processing power, as opposed to by thousands of distributed nodes.[156] As a result, they may provide a more scalable platform. However, the TTP or trusted nodes will need to invest in traditional security, to protect against hackers gaining access to the ledger or DoS attacks from taking down nodes.

3.3 Governance and Control

[61] A final aspect of trust relates to control over platform design: who has the power to determine how the platform operates? This raises issues of blockchain governance: who can change the platform and under what circumstances should past entries in the ledger be changed. In this section,

[155] *See id.*

[156] *See id.*

we first consider protocol changes, before turning to the reversibility of past transactions, and the role of service providers.

3.3.1. Developers and Protocol Changes

[62] From a technical perspective, governance involves the groups discussed above—users, miners and nodes—as well as a fourth group, the *developers*, who produce the software that nodes and miners run to support the blockchain.[157] In practice, blockchain governance will differ per platform. In the current cryptocurrency context, these four groups form a community around a shared interest in maintaining, and increasing, the value of the coin. Each group can use informal governance mechanisms to express its preferences. Examples include discussions of technical improvement proposals,[158] user-wide votes on protocol changes,[159] miner-implemented *soft forks*,[160] and ultimately, hard forks that lead to competing, alternative cryptocurrencies.[161]

[157] *See* NISTIR OVERVIEW, *supra* note 6, at 44.

[158] *See, e.g.*, *Bitcoin Improvement Proposals*, GITHUB, https://github.com/bitcoin/bips [https://perma.cc/2P39-THWT] (providing an example of a governance mechanism used to express a preference); *see also Ethereum Improvement Proposals*, GITHUB, https://github.com/ethereum/EIPs/issues/ [https://perma.cc/S629-ZP7D] (citing as an example of a governance mechanism).

[159] *See, e.g.*, *CarbonVote*, CARBON VOTE, http://carbonvote.com/ [https://perma.cc/JYM3-NFH3] (describing how user-wide voting works).

[160] *See* De Filippi & Loveluck, *supra note* 129, at 26.

[161] *See* NISTIR OVERVIEW, *supra* note 6, at 33–34.

[63] For example, the Bitcoin source code is developed in an open-source manner using GitHub.[162] Anybody can view the code and propose improvements.[163] However, only a small group, known as the *core developers* are able to make changes to the version of the software known as *Bitcoin Core*.[164] Thus, the Bitcoin platform is not fully open/permissionless at this code development level. Ethereum code is similarly developed through an open-source process, with the Ethereum Foundation having ultimate responsibility for code changes.[165] Ethereum's founder, Vitalik Buterin is a member of the foundation and actively participates in governance discussions.[166]

Table 5. The Bitcoin Application of Blockchain Technology

No.	Group	Function	Permission
i.	Users	Propose new transactions	Open: Anyone can join the network and send and receive Bitcoin.
ii.	Nodes	Store copies of the DL	Open: Anyone can download the software and run a Bitcoin node.

[162] *See Bitcoin Development*, BITCOINCORE, https://bitcoin.org/en/development [https://perma.cc/2VKT-8QZD]. Github is a web-based service that provides cloud-hosted distributed revision control and source code management for user-uploaded software projects. Anyone can register an account, create a software repository, and/or begin suggesting edits to other public repositories.

[163] *See How to Contribute Code to Bitcoin Core*, BITCOINCORE, https://bitcoincore.org/en/faq/contributing-code/ [https://perma.cc/C8Z7-349G].

[164] *See* Catherine Martin Christopher, *The Bridging Model: Exploring the Roles of Trust and Enforcement in Banking, Bitcoin, and the Blockchain*, 17 NEVADA L.J. 139, 150 (2016).

[165] *See* Nick Tomaino, *The Governance of Blockchains*, THE CONTROL, (Feb. 28, 2017) https://thecontrol.co/the-governance-of-blockchains-5ba17a4f5da6 [https://perma.cc/J6MG-V4NY].

[166] *See About the Ethereum Foundation*, ETHEREUM, https://www.ethereum.org/foundation [https://perma.cc/DR79-HWKS].

iii.	Miners	Propose new blocks	Open: Anyone can (attempt to) mine new blocks and broadcast them to the P2P network
iv.	Developers	Change the Bitcoin 'core' software	Closed: only a small group of core developers can change the 'core' code.

[64] Changes to the code encompass technical issues, like bug fixes, but also platform design decisions that have direct operational impact, such as the size of the blocks that determine the system's throughput. As a result, the platform requires users to place some level of trust in the developers.[167]

[65] Nonetheless, the developers' power is limited by the possibility of *hard forks*.[168] Anyone can take the code from GitHub and *fork* it, meaning they can write a new version—typically an extension—of the software and make it available for others to download.[169] There are several versions of the Bitcoin software available that differ in terms of properties or functionality.[170]

[66] This means that anyone can propose new technical features or platform designs, by writing new software with a different block size or consensus protocol. The deliberate creation of a new version of software that is incompatible with the existing software, for instance, because it has

[167] *See* Christopher, *supra* note 164, at 150; *see also* De Filippi & Loveluck, *supra* note 129, at 5 (discussing the extent to which trust plays into blockchain).

[168] *See* NISTIR OVERVIEW, *supra* note 6, at 33–34.

[169] *See id.*

[170] *See, e.g.*, *Fair Distribution*, BITCOIN GOLD, https://bitcoingold.org/ [https://perma.cc/6VYY-DFV3].

a different consensus protocol, is called a *hard fork*.[171] In the case of a hard fork, miners and nodes must decide which version of the software they want to run.[172] Different miners and nodes may choose to run different versions of the software. If they do, this creates two separate blockchains that track two different cryptocurrencies.[173] Both start from the last block before the fork but will add different blocks going forward. As a result, they will track two different cryptocurrencies.[174]

[67] In practice, software is forked to provide some different functionality or capability.[175] To have impact, the resulting software must be adopted.[176] This means that each fork will need to attract miners, nodes, and users to their version of the software. The value of each currency resulting from a fork, is determined by supply and demand on currency exchanges.[177] This, in turn, depends on each currency's ability to attract miners, intermediaries, and ultimately, users.[178] The result is a system of

[171] *See* NISTIR OVERVIEW, *supra* note 6, at 33–34.

[172] *See id.*

[173] *See id.*

[174] *See* De Filippi & Loveluck, *supra* note 129, at 7 (providing for examples of such forks in relation to Bitcoin's block size). *See generally What is Segwit*, SEGWIT, https://www.coindesk.com/information/what-is-segwit/ [https://perma.cc/594Y-RQ5N] (last updated Feb. 22, 2018).

[175] *See* NISTIR OVERVIEW, *supra* note 6, at 33–34.

[176] *See id.*

[177] *See id.*

[178] *See* Kyle Torpey, *You Really Should Run a Bitcoin Full Node: Here's Why*, BITCOIN MAG. (Mar. 9, 2017, 1:37 PM), https://bitcoinmagazine.com/articles/you-really-should-run-full-bitcoin-node-heres-why/ [https://perma.cc/8JPC-XGWL]; Aaron van Wirdum, *On Consensus, or Why Bitcoin's Block-Size Presents a Political Trade-off*, BITCOIN MAG. (Jan. 15, 2016, 2:51 PM), https://bitcoinmagazine.com/articles/on-consensus-or-why-bitcoin-s-block-size-presents-a-political-trade-off-1452887468/ [https://perma.cc/2LNU-WMR4].

checks and balances that should generally favour incremental protocol change.

[68] In more closed/permissioned and centralised instantiations of a DL, the code and its updates might be defined by agreements between the participants involved, including contractual agreements. Governance issues should be more straightforward where fewer parties are involved.

3.3.2 Reversibility of Past Transactions

[69] A second issue of blockchain governance relates to the reversibility of past transactions recorded on the blockchain. As discussed above, the blockchain aims to create a persistent, tamper-evident record of relevant transactions.[179] However, the ledger is not technically *immutable*.[180] The nodes of any given platform could undertake a coordinated effort to *correct* their local versions of the ledger and undo specific past transactions they considered inappropriate.[181] The nodes would effectively *fork* to a new version of the blockchain without the offending transactions. Although this goes against the general aim of creating a persistent record, the nodes may agree that it is appropriate in exceptional circumstances.

[70] How easy this is to achieve differs according to the blockchain platform's design. On an open, distributed platform, establishing a hard fork is costly, both in terms of arranging cooperation between nodes and re-hashing previous blocks where required.[182] A party seeking to reverse a past transaction would need to propose a network-wide hard fork.[183] There

[179] *See* discussion *supra* Section 2.1.

[180] *See* NISTIR OVERVIEW, *supra* note 6, at 33–34.

[181] *See id.*

[182] *See* Jeremy M. Sklaroff, *Smart Contracts and the Cost of Inflexibility*, 166 U. PA. L. REV., 263, 277 (2017).

[183] *See* NISTIR OVERVIEW, *supra* note 6, at 33–34.

is no guarantee that nodes will agree to fork. The difficulties are illustrated by the example of the Ethereum DAO, set out below in Section 6.6.[184]

[71] Conversely, with a centralised platform, it should be easier to arrange a corrective fork. The TTP or small group of trusted nodes can agree to correct the ledger, which would also be less costly if the consensus protocol does not require PoW. Thus, a party seeking to reverse a past transaction would only need to submit a request to, and obtain approval of, the TTP or group of trusted nodes. As a result, centralised platforms can support reversibility better.

[72] A potentially simpler way to reverse the effects of a past transaction is for the parties to enter a *correcting transaction*, to be recorded in a subsequent block.[185] This second transaction would negate the effect of the initial transaction. However, this requires either both parties' cooperation, or at least access to the counter-party's private key if enforced externally by a third-party. As a result, this is not an option where one of the parties contests the reversal. Companies are also exploring the possibility of *editable* blockchains, changing the way hash pointers link blocks so that a small number of authorised parties can change past blocks.[186]

3.3.3 Service Provider Considerations

[73] A final trust issue relates to the roles of service providers involved in the blockchain platform. As noted above, many users rely on intermediaries, such as online—or *hot*—wallets, as an interface to a

[184] *See* discussion *infra* Section 6.6.

[185] *See* Jeff John Roberts, *Why Accenture's Plan to 'Edit' the Blockchain Is a Big Deal*, FORTUNE (Sept. 20, 2016), http://fortune.com/2016/09/20/accenture-blockchain/ [https://perma.cc/V7GX-7VBY].

[186] *See Editing the Uneditable Blockchain: Why Distributed Ledger Technology Must Adapt to an Imperfect World*, ACCENTURE (2016), https://newsroom.accenture.com/content/1101/files/Cross-FSBC.pdf [https://perma.cc/77E4-ZXGX].

blockchain system.[187] This requires users to place some degree of trust in such service providers, since the provider determines the nature of the service and manages its operation.[188]

[74] However, service providers may also be directly involved in the operation of a blockchain platform.[189] In such cases, sometimes termed *Blockchain-as-a-Service* (BaaS), a third party provides aspects of the platform's infrastructure.[190] This can range from a completely managed DL, to the hosting of particular nodes, as well as supporting infrastructure such as identity key management services.[191] While BaaS is an emerging area, the major cloud providers are active in this space.[192]

[75] BaaS raises additional trust and governance considerations, given the service provider's control over the technical infrastructure.[193] Ultimately, any concerns will depend on the precise nature of the service offered, and the degree of power the service provider has over the entire system. A provider managing a single node as part of a large, federated

[187] *See* Kevin D. Werbach, *Trust, But Verify: Why the Blockchain Needs the Law*, BERKELEY TECH. L.J. (forthcoming 2018) (manuscript at 27).

[188] *See id.*

[189] *See* Lucas Mearian, *Amazon Joins List of Blockchain-as-a-Service Providers*, COMPUTERWORLD FROM IDG (Jun. 1, 2018, 12:41 PM), https://www.computerworld.com/article/3278088/blockchain/amazon-joins-list-of-blockchain-as-a-service-providers.html [https://perma.cc/AK22-9LZD].

[190] *See* Jatinder Singh & Johan David Michels, *Blockchain as a Service (BaaS): Providers and Trust*, 2018 IEEE EUROPEAN SYMP. ON SECURITY & PRIVACY WORKSHOPS (EUROS&PW) (2018).

[191] *See id.* at 12.

[192] *See* Mearian, *supra* note 189.

[193] *See* Singh & Michels, *supra* note 190 (arguing that service providers detract from one of blockchain's most attractive attributes, a decentralised ledger).

network of nodes raises different considerations to a service provider that hosts all the nodes of a network. There are strong incentives for service providers to ensure the integrity of their platforms, as their reputation is crucial to the longevity of their business. Providers may also be able to use advances in technical mechanisms, such as trusted execution environments *secure enclaves* that aim to provide a technical guarantee that specific code was executed.[194]

4. Visibility and Identity

[76] This section considers two further questions of blockchain platform design: (i) who can see the record of transactions stored on the blockchain and (ii) to what extent can the blockchain's users be identified.

4.1 Visibility of the Record: Public and Private Platforms

[77] As set out above, early cryptocurrencies are permissionless at the level of nodes and miners, meaning anyone can download the entire blockchain archive.[195] Further, all new transactions are broadcast to all nodes for the purpose of mining new blocks.[196] As a result, all blockchain transactions are publicly visible.[197] For instance, the latest Bitcoin transaction records are available to view online.[198] This record includes the sending Bitcoin address, the receiving Bitcoin address, the amount of Bitcoin, and a timestamp.[199] A Bitcoin address is a 26–35 digit

[194] *See* Singh & Michels, *supra* note 190, at 14.

[195] *See* discussion *supra* Section 3.

[196] *See* discussion *supra* Section 3.1.2.

[197] *See* Nakamoto, *supra* note 34, at 6.

[198] *See Latest Blocks*, BLOCK EXPLORER https://blockexplorer.com/ [https://perma.cc/XH3Q-H2AK] (listing the latest blockchain blocks and transactions in real time).

[199] *See id.*

combination of letters and numbers which is generated based on a hash of a user's public key.[200] Thus, the public can see that a particular address is sending an amount of Bitcoin to another address, but without information linking the addresses to any real-world identities.[201]

[78] This public visibility of all transaction data may prove a barrier to the adoption of open, distributed platforms.[202] For certain use cases, parties may not be willing to share data about their transactions publicly, particularly where access to transaction data may provide a commercial advantage. For instance, if a blockchain were used for trading shares, competitors may be able to discern each other's trading patterns.[203]

[79] Conversely, more centralised systems can limit visibility of the blockchain to certain parties, resulting in a *private* blockchain.[204] If a permissioned system is stored by a TTP, it can withhold access to the blockchain archive and grant permission to view blocks or entries only in specific cases.[205] However, such a system asks for a higher degree of trust from users, since only the TTP will know whether the blockchain has been

[200] *See Blockchain Address 101: What are Addresses on Blockchains?*, BLOCKGEEKS, https://blockgeeks.com/guides/blockchain-address-101/ [https://perma.cc/HL4Z-QTYA].

[201] *See* NISTIR OVERVIEW, *supra* note 6, at 46.

[202] *See Technology Overview*, ZCASH, https://z.cash/technology/index.html [https://perma.cc/D7TQ-74CX] (stating that there are platforms that aim to use distributed blockchains without a publicly visible record. For example, Zcash features a blockchain that only stores encrypted data and uses a technique called 'zero knowledge proofs' for validation, without revealing the data).

[203] *See Report: The Distributed Ledger Technology Applied to Secured Markets*, EUR. SEC. MKT. AUTHORITY, 11 (Feb. 7, 2017), https://www.esma.europa.eu/system/files_force/library/dlt_report_-_esma50-1121423017-285.pdf [https://perma.cc/24K7-QMSK].

[204] *See* Buterin, *Public and Private Blockchain*, *supra* note 138.

[205] *See id.*

tampered with.[206] Similarly, in permissioned systems using trusted nodes, each trusted node stores and is able to view the entire blockchain.[207] Since the blockchain is stored across multiple nodes, this type of system can limit visibility, while being more tamper-evident than systems with a single TTP.[208]

4.2 Identity of Participants

[80] In the physical world, we use birth certificates, passports, and other Government-issued official documents to prove our identity.[209] On online networks, we often start from real-world documents, presenting them as credentials to institutions, for example when enrolling as a student at a university or registering with Airbnb. This is the basis for authentication, proving that you are who you say you are and allowing an electronic identity to be associated with a validated person and their real-world identity. Part of the establishment of an electronic identity is to associate electronic credentials such as a secret password or biometrics with the validated person.

[81] As noted above in Section 0, blockchains use PKI to authenticate users' identities.[210] Unlike Government-issued IDs, revealing a public key need not in general reveal the real-world identity of the associated party.[211] As a result, even though each transaction record is public, Bitcoin and

[206] *See id.*

[207] *See id.*

[208] *See id.*

[209] *See, e.g.*, *Acceptable Documents*, U.S. CITIZENSHIP & IMMIGR. SERV., https://www.uscis.gov/i-9-central/acceptable-documents [https://perma.cc/8HEB-ERN5] (listing various documents that can be used to prove your identity).

[210] *See* discussion *supra* Section 2.2.

[211] *See* Nakamoto, *supra* note 34, at 6.

Ethereum users enjoy a level of anonymity by using their addresses as pseudonyms.[212]

[82] To bolster their privacy, users could generate a new public key and address for each new transaction.[213] The public could still see that the Bitcoins had moved to a new address, but they would not know who controlled the new address. There are also other online services to help users mask their transactions, known as bitcoin *mixing* or *laundry*.[214]

[83] In most cases, outside observers will not be able to determine the real-world identity of the parties to a transaction. Nonetheless, the two can be linked through a user's voluntary disclosure.[215] For instance, if a user pays an online merchant in Bitcoin, that merchant will likely ask for the customer's name, email address, and possibly real-world address.[216] Further, it may be possible to use other methods to de-anonymise users, such as by linking public keys to the IP addresses where the transactions are generated.[217] For example, a 2018 study claimed to identify 95 million Bitcoin addresses as belonging to 14 million identified individuals.[218]

---

[212] *See id.*

[213] *See* Jaume Barcelo, *User Privacy in the Public Bitcoin Blockchain*, 6 J. LATEX CLASS FILES 1, 1–2 (2017).

[214] *See, e.g.*, Thibault de Balthasar & Julio Hernandez-Castro, *An Analysis of Bitcoin Laundry Services*, 10674 LECTURE NOTES IN COMPUTER SCI., 297, 297–98 (2017) (describing various mixer and laundry services).

[215] *See* Fergal Reid & Martin Harrigan, *An Analysis of Anonymity in the Bitcoin System*, *in* SEC. & PRIV. IN SOC. NETWORKS 197, 212 (Yaniv Altshuler et al. eds. 2013).

[216] *See id.* at 210.

[217] *See* Alex Biryukov et al., *Deanonymisation of Clients in Bitcoin P2P Network*, 2014 PROC. ACM SIGSAC CONF. ON COMPUTER AND COMM. SEC. 16, 21.

[218] *See Bitfury De-Anonymises Millions of Bitcoin Transactions and Addresses*, TRUSTNODES (Jan. 9, 2018, 3:39PM), http://www.trustnodes.com/2018/01/09/bitfury-de-anonymises-millions-bitcoin-transactions-addresses [https://perma.cc/QFR6-E5KK].

Anyone who knows the real-world identity associated with a Bitcoin address, can review the entire transaction history associated with that address.[219]

[84] Future blockchain platforms may instead require the real-world identity of participants to be established, rather than hidden. This will likely depend on the functionality they seek to offer and on regulatory requirements. For instance, a number of organisations are promoting the use of blockchain to allow individuals to manage their identity.[220] In such cases, an individual would probably need to verify their identity using traditional methods to a TTP, who would then vouch for that individual's identity.[221]

5. Smart Contracts

[85] Section 3.1 above described the core components of blockchain software that enable users to submit transactions securely to a tamper-evident data structure of linked blocks.[222] Some blockchain applications might feature single, standalone transactions, which are relatively simple to incorporate into a ledger, such as a Bitcoin transfer from one party to another. Other applications might require more complicated interactions, such as a series of related, sequential or conditional transactions.[223] For

[219] *See* Barcelo, *supra* note 213, at 2.

[220] *See* Reed et al., *supra* note 16, at 14–15 (discussing the notion of self-sovereign identity).

[221] *See, e.g.*, *Public Key Certificates*, MICROSOFT (May 30, 2018), https://docs.microsoft.com/en-us/windows/desktop/seccertenroll/about-x-509-public-key-certificates [https://perma.cc/E5ZV-2VFQ] (defining "public key certificates"); *CA Certificate*, MICROSOFT SEC. GLOSSARY (May 30, 2018), https://docs.microsoft.com/en-us/windows/desktop/SecGloss/c-gly#-security-certification-authority-gly [https://perma.cc/VRA2-E724] (defining "CA certificate"). *See generally* Bacon et al., *supra* note 12 (providing details on Certification Authorities).

[222] *See supra* notes 62–64 and accompanying text.

[223] *See* NISTIR OVERVIEW, *supra* note 6, at 35.

example, an international supply chain would require a great deal of documentation to be verified as goods travel from source to destination. Their progress could be documented on a blockchain, to record that the goods have arrived at and departed from various intermediate locations.

[86] Smart contracts can be used to automate such a series of transactions.[224] Introduced by Szabo in 1994, a smart contract is "a computerised transaction protocol that executes the terms of a contract."[225] The term *smart contract* may confuse lawyers, since it does not refer to a legal contract, see Section 6.1 below. Instead, the term essentially refers to a computer program that automatically brings about some specified action, such as carrying out transfers of, or executing other actions relating to, digital assets according to a set of pre-specified rules.[226] As a result, smart contracts can be used to automate agreements between parties according to the set of instructions written into their code.[227] In many ways, smart contracts resemble the stored procedures and/or triggers, *event-condition-action* rules, which are common in relational databases.[228]

---

[224] *See* Dawei Ding, *Smart Contracts to Enable Automated Transactions*, BCF BUS. L. (Mar. 23, 2018), http://www.bcf.ca/en/current-affairs/907/smart-contracts-to-enable-automated-transactions [https://perma.cc/LDV5-M4YF].

[225] Nick Szabo, *Smart Contracts*, PHONETIC SCI., AMSTERDAM (1994) [hereinafter Szabo, *Smart Contracts*], http://www.fon.hum.uva.nl/rob/Courses/InformationInSpeech/CDROM/Literature/LOTwinterschool2006/szabo.best.vwh.net/smart.contracts.html [https://perma.cc/KP3Y-AURX]; *see also* Nick Szabo, *The Idea of Smart Contracts*, PHONETIC SCI., AMSTERDAM (1997) [hereinafter Szabo, *Idea of Smart Contracts*], http://www.fon.hum.uva.nl/rob/Courses/InformationInSpeech/CDROM/Literature/LOTwinterschool2006/szabo.best.vwh.net/idea.html [https://perma.cc/4858-8NNY] (discussing smart contracts and the kinds of contractual clauses involved).

[226] *See* Szabo, *Smart Contracts*, *supra* note 225; Buterin, ETHEREUM WHITE PAPER *supra* note 109, at 1.

[227] *See* NISTIR OVERVIEW, *supra* note 6, at 35.

[228] *See* Konstantinos Christidis & Michael Devetsikiotis, *Blockchains and Smart Contracts for the Internet of Things*, 4 IEEE ACCESS, 2296–97 (2016).

[87] Smart contracts thus aim to capture in software the semantics of potentially complex interactions.[229] The workflows that represent a complex interaction may be represented as a number of transactions, triggered as appropriate as the interaction progresses. The challenges involved in correctly capturing these semantics as smart contracts include validation and verification.[230]

[88] A further platform design consideration is therefore the extent to which the platform will support user-made smart contracts, alongside predefined smart contracts that form part of the platform's basic functionality. The more a blockchain platform supports smart contracts, the more scope users have to use the platform for different purposes. Developers who want to create a simple blockchain for a predetermined purpose may opt to offer limited support for smart contracts, or only support smart contracts made of predefined components. In Bitcoin, the functionality relating to transactions is brought about through a series of scripts or programs.[231] These scripts can be used to control Bitcoins thereby supporting basic smart contracts with limited functionality.[232]

[89] Conversely, developers can also allow their platform to support many types of smart contract.[233] A key feature of Ethereum is that it supports *Turing-complete* smart contracts.[234] Turing-completeness means that the language is as fully-featured as a general programming language

[229] *See, e.g.*, NISTIR OVERVIEW, *supra* note 6, at 35.

[230] *See* Daniele Maggazeni et al., *Validation of Smart Contracts: A Research Agenda*, IEEE COMPUT. SOC'Y, at 50 (Sept. 2017).

[231] *See* Aviv Zohar, *Bitcoin: Under the Hood*, 58 COMM. ACM, 9, 104, 110–11 (2015); *see also* NISTIR OVERVIEW, *supra* note 6, at 40.

[232] *See* Buterin, ETHEREUM WHITE PAPER, *supra* note 109, at 11–12.

[233] *See id.* at 12.

[234] *See id.* at 1, 12–13.

and is not restricted in what it can compute.[235] As a result, Ethereum can be used as a platform to run a wide array of applications expressed in smart contracts,[236] as opposed to Bitcoin's *Script* which is deliberately limited in scope.[237] Given this, some authors differentiate between Ethereum as a platform and Bitcoin as a digital currency.[238]

[90] In terms of operation, as part of the block mining process, a transaction, i.e. a ledger entry, being processed might trigger a smart contract. This results in the smart contract's code being executed, where the triggering and any resulting transactions, i.e. contract outputs, are encoded in the block along with any other transactions forming the block.[239] As part of the block validation process, all nodes will also execute and verify the contract to ensure that the smart contract was properly executed.[240] In other words, as per Buterin: "if a transaction is added into block B the code execution spawned by that transaction will be executed by all nodes, now and in the future, that [. . .] validate block B."[241] In this way, smart contracts enable consensus regarding

[235] *See id.* at 28, 34.

[236] *See id.* at 34.

[237] *See* Andreas M. Antonopoulos, *Mastering Bitcoin: Chapter 5. Transactions*, O'REILLY, https://www.oreilly.com/library/view/mastering-bitcoin/9781491902639/ch05.html [https://perma.cc/GH3T-UJRU].

[238] *See* Paolo Tasca et al., *Taxonomy of Blockchain Technologies. Principles of Identification and Classification*, ALLQUANTOR (May 31, 2017), https://allquantor.at/blockchainbib/pdf/tasca2017ontology.pdf [https://perma.cc/4GNH-346K].

[239] *See* Buterin, ETHEREUM WHITE PAPER, *supra* note 109, at 7.

[240] *See id.* at 10.

[241] *White Paper: A Next-Generation Smart Contract and Decentralized Application Platform*, GITHUB, https://github.com/ethereum/wiki/wiki/White-Paper#a-next-generation-smart-contract-and-decentralized-application-platform [https://perma.cc/BL32-R5WY].

computation,[242] given that generally all nodes in a network will verify a contract's execution.[243] Since smart contract code is generally run on all nodes on the network, it is publicly visible to all participants, meaning the code can be inspected and re-used by other participants.[244]

III. BLOCKCHAIN AND THE LAW

6. Legal Analysis

[91] In Part One, above, we saw that blockchain technology can be applied in various ways to create platforms with different features, including with regard to:

(i) Access: who can propose new transactions to be added to the ledger;
(ii) Control:
  a. Storage: who stores a copy of the ledger;
  b. Mining and consensus: how to create new blocks and determine when blocks should be added to the existing ledger;
  c. Governance: who controls the platform's underlying software;
(iii) Visibility: who can view the ledger;
(iv) Identity: whether users are identifiable; and,
(v) Automation: whether the platform supports smart contracts.

[92] In this section we argue that these variables may be significant from a legal perspective. To illustrate this point, we look at various ways in which blockchain technology is being used to create structures that resemble existing legal concepts, including contracts, companies, and

[242] *See* Ahmed Kosba et al., *Hawk: The Blockchain Model of Cryptography and Privacy-Preserving Smart Contracts*, IEEE SYMP. ON SEC. & PRIV. 839, at 839 (2016).

[243] *See* Buterin, ETHEREUM WHITE PAPER, *supra* note 109, at 4, 6–7.

[244] *See id.* at 1.

securities. Below, we consider how existing law will apply to these new blockchain-based structures. We will consider, in turn, issues arising under (i) contract law, (ii) data protection law, (iii) securities law, (iv) property law, (v) intellectual property and finally (vi) company law. For each area, we illustrate how the legal analysis is affected by the way in which blockchain technology is deployed in a specific use case.

6.1 Smart Contracts and Contract Law

6.1.1 Formation: Is a Smart Contract a Contract?

[93] The term *smart contract* is arguably misleading, since it refers to automatically executing computer code, see Section 5.[245] This raises the question whether a smart contract qualifies as a legal contract.

[94] A legal contract is commonly defined as a legally enforceable agreement or promise.[246] It is typically formed through voluntary offer and acceptance, as well as—in common law jurisdictions—consideration: the value offered by each party.[247] Many types of contracts can be established in any form: orally, in writing, or through actions, such as assenting to terms in electronic media by clicking, also known as *clickwrap agreements*.[248] However, the law in some countries may require that certain types of contracts be recorded in a specific form or be entered into

[245] *See* discussion *supra* Section 5.

[246] *See, e.g.*, *Contract*, BLACK'S LAW DICTIONARY (2d ed. 2018), https://thelawdictionary.org/contract/ [https://perma.cc/FRQ8-H94Y] (providing a definition of contract).

[247] *See* RESTATEMENT (SECOND) OF CONTRACTS § 1 cmt. b, d (AM. LAW INST. 1981); *see also* RESTATEMENT (SECOND) OF CONTRACTS § 17 (AM. LAW INST. 1981); RESTATEMENT (SECOND) OF CONTRACTS § 71 (AM. LAW INST. 1981).

[248] *See, e.g.*, W. Kuan Hon et al., *Negotiated Contracts for Cloud Services*, *in* CLOUD COMPUTING L. (Christopher Millard ed., 2013), 76-77; *see* RESTATEMENT (SECOND) OF CONTRACTS § 4 (AM. LAW INST. 1981).

in a particular manner, for instance requiring real estate transactions to be recorded in writing and witnessed by a notary.[249]

[95] One could argue that a smart contract is not a legally enforceable *promise*, but an automated mechanical process.[250] While this may be true at the level of the computer-readable code, it is unlikely to reflect smart contract use in practice. In reality, the creator of a smart contract will ordinarily need to explain his offer to human counter-parties in human-intelligible language. This explanation can form the basis of the agreement between the parties and thereby determine the terms of the contract.

[96] For example, assume party A sets up a crypto-asset exchange contract on Ethereum. The smart contract's instructions are that if a counter-party pays 1 ETH into a specified address, it will in return provide them with a 'CryptoKitty,' a unique cartoon cat, stored on the blockchain.[251] In order to attract human counter-parties to this offer, A will have to explain it to them in a language they can understand, for instance through a website like https://www.cryptokitties.co/ or other user interface. In doing so, A will communicate the details of her offer. By engaging with the smart contract—in this instance, paying 1 ETH to a specific address—B expresses acceptance, assenting to the terms of A's offer as explained in the user interface.[252] Even though the underlying

[249] *See* RESTATEMENT (SECOND) OF CONTRACTS § 110 (AM. LAW INST. 1981).

[250] *See* Kevin Werbach & Nicolas Cornell, *Contracts Ex. Machina*, DUKE L.J. 313, 339–40 (2017).

[251] *See* Fitz Tepper, *People Have Spent Over $1M Buying Virtual Cats on the Ethereum Blockchain*, TECH CRUNCH (Dec. 3, 2017), https://techcrunch.com/2017/12/03/people-have-spent-over-1m-buying-virtual-cats-on-the-ethereum-blockchain/ [https://perma.cc/N298-TM24].

[252] *See* Werbach & Cornell, *supra* note 250, at 340–41.

smart contract code may technically be visible,[253] many users will likely *de facto* rely on A's other communications.

[97] Parties offering smart contracts may seek, via disclaimers or other provisions in their Terms of Service, to limit their contractual obligations solely to the computer-readable code.[254] For instance, in 2016, the website of *The DAO*—a collection of smart contracts set up on the Ethereum blockchain—stated explicitly in its terms of service that the smart contract was the valid legal agreement.[255] Any human-readable documents or explanations on the accompanying website were "merely offered for educational purposes" and could not override the terms of the code.[256]

[98] Whether such disclaimers are legally binding may be tested in court. On the one hand, standard contracts commonly include provisions that exclude all representations outside of the contract terms and provide a hierarchy between various legal documents.[257] Moreover, given that smart contract code is typically visible to all nodes on the blockchain, their function should be legible to a skilled programmer/developer. On the other hand, simply publishing machine-readable code may not provide sufficient

[253] *See, e.g.*, *Contract 0x06012c8cf97BEaD5deAe237070F9587f8E7A266d*, ETHERSCAN, https://etherscan.io/address/0x06012c8cf97bead5deae237070f9587f8e7a266d#code [https://perma.cc/6WFM-YVYT].

[254] *See* Werbach & Cornell, *supra* note 250, at 350–51.

[255] *See Explanation of Terms and Disclaimer*, THE DAO (Apr. 27, 2016), https://web.archive.org/web/20160704190119/https://daohub.org/explainer.html [https://perma.cc/EWT9-PUTY].

[256] *Id.*

[257] *See* Gregory Klass, *Interpretation and Construction in Contract Law*, 1, 26 (Jan. 2018) (draft manuscript) (citing W. W. W. Assoc. v. Giancontieri, 566 N.E.2d 639, 642 (N.Y. 1990)) http://scholarship.law.georgetown.edu/facpub/1947 [https://perma.cc/XUU2-7J9W]; *see also Hierarchy of Documents Sample Clauses*, LAW INSIDER, https://www.lawinsider.com/clause/hierarchy-of-documents [https://perma.cc/EJH4-UUGG].

notice of contractual terms to non-expert counter-parties.[258] Further, if there is an obligation that some term should be *fair and reasonable*—typically an exclusion or limitation of liability—that has to be assessed individually in relation to the parties.[259] A term might be generally fair and reasonable, but not so in the particular circumstances.[260]

[99] Given the above, the code may be more likely to be binding in B2B-cases, than in B2C or C2C cases. Further, the code could be binding if the counter-party also uses a smart contract to express their assent, i.e. a machine-to-machine smart contract. The two smart contracts will find agreement only if there is a set of computer-readable terms that are acceptable to both parties. In such cases, there is a strong argument for limiting the contract's obligations to those expressed in the code.

[100] However, even machine-to-machine smart contracts' terms may not be legally binding in all cases.[261] Many jurisdictions limit parties' contractual freedom by determining that certain contractual terms are not enforceable, for instance in order to address power asymmetries between the contracting parties—such as between producers/retailers and consumers; landlords and tenants; or employers and employees—or because the terms are otherwise unconscionable.[262] For example, a smart contract that does not give a consumer a right of withdrawal or refund may fall foul of consumer protection law.

[258] *See* Pierluigi Cuccuru, *Beyond Bitcoin: An Early Overview on Smart Contracts*, INT'L J.L. INFO. TECH. 179, 188–89 (2017).

[259] *See Cleaver v. Schyde* (2011) EWCA Civ 929, [2011] 2 P. & C.R. 21 (UK).

[260] *See id.*

[261] *See* Max Raskin, *The Law and Legality of Smart Contracts*, 1 GEO. L. TECH. REV. 305, 325 (2017).

[262] *See id.* at 325, 328; *see also* Werbach & Cornell, *supra* note 250, at 347, 350.

6.1.2 Performance: Can Smart Contracts be Breached?

[101] Since smart contracts self-execute pre-determined code, it could be argued that they cannot be breached.[263] The smart contract will always do exactly what it says in its code. However, as noted above, the legal contract between the parties is likely to include obligations beyond the code itself, based on other communications.[264] If that is the case, not all of the obligations can be captured fully and correctly by the underlying smart contract. As a result, there may be a mismatch between what the parties have agreed and what the smart contract's code executes, resulting in non-performance.[265] Smart contracts are by their nature limited to those contractual terms that can be specified in computer-readable code,[266] and further limited by any constraints imposed by the blockchain system in which the contract operates. As a result, they are unable to capture the real-world complexity of all but the simplest transactions.[267]

[102] Contractual performance[268] in transactions involving digital assets, such as the exchange of crypto-assets described above, is relatively straightforward to describe and measure. The ledger then provides a reliable record of the transactions and contracts executed.[269] However, the complexity of transactions is magnified if performance involves off-chain,

[263] *See* Raskin, *supra* note 261, at 322.

[264] *See* Werbach & Cornell, *supra* note 250, at 331, 342.

[265] *See* Eliza Mik, *Smart Contracts: Terminology, Technical Limitations and Real-World Complexity*, 9.2 L., INNOVATION, & TECH. 1, 11 (2017).

[266] *See* Werbach & Cornell, *supra* note 250, at 343.

[267] *See* Karen Levy, *Book-Smart, Not Street-Smart: Blockchain-Based Smart Contracts and the Social Workings of Law*, 3 ENGAGING SCI., TECH., & SOC'Y 1, 10 (2017); *see also* Mik, *supra* note 265, 22 (2017).

[268] I.e. the performance of a legal contract, not performance in the computer science sense.

[269] *See* Levy, *supra* note 268, at 2.

real world assets, such as giving access to a vehicle through a smart lock.[270] In such cases, performance is harder to assess; the quality of the service may be below a reasonable standard, e.g. the vehicle may not start, or otherwise differ from reasonable expectations.[271]

[103] Where performance is disputed, the parties may seek to address this through negotiation, arbitration, or litigation. Thus, while smart contracts might simplify execution, they will not prevent contractual disputes. Nonetheless, the blockchain's consensus mechanisms may give guarantees about the smart contracts that were executed and the surrounding circumstances.

6.1.3 Modification and Enforcement: Are Mistakes in Smart Contracts Reversible?

[104] The code of smart contracts is subject to human error and is therefore likely to contain bugs.[272] Mistakes in the code may prove costly.[273] For instance, if an attacker exploits a poorly-written smart contract, any resulting transactions are written into the tamper-evident blockchain. The offering party can replace the smart contract for future transactions, but cannot edit the existing smart contract or easily reverse its effects.[274] For example, in 2017, a user accidentally triggered a flaw in the code of a smart contract service called Parity.[275] The service provided

[270] *See* Mik, *supra* note 265, at 22.

[271] *See* Raskin, *supra* note 261, at 326.

[272] *See* Werbach & Cornell, *supra* note 250, at 365.

[273] *See* Mik, *supra* note 265, at 11.

[274] *See id*. at 7, 11.

[275] *See, e.g.*, Alex Hern, *$300m in Cryptocurrency Accidentally Lost Forever Due to Bug*, THE GUARDIAN (Nov. 12, 2017, 6:29 PM), https://www.theguardian.com/technology/2017/nov/08/cryptocurrency-300m-dollars-stolen-bug-ether?CMP=share_btn_tw [https://perma.cc/7TA5-3YKF].

multi-signature wallets for Ethereum.[276] As a result, an estimated 1m ETH, worth U.S. $300 million at the time, was permanently frozen in the wallets, with no way for users to access their funds.[277]

[105] Mistakes in legal contracts may be costly too. However, since a legal contract is not self-executing, a party can withhold performance and renegotiate terms.[278] In the event of an on-going dispute, the parties can turn to litigation. A judge may then be able to correct obvious mistakes or incompleteness in contract language through interpretation, by assessing the intent of the parties.[279] Thus, parties can seek to correct mistakes in legal contracts after signing.

[106] Resolving mistakes in smart contracts is more complicated. Since a smart contract is self-executing, its automated performance is written into the blockchain.[280] As outlined in Section 3.3.2, reversing past blockchain transactions would require either a *correcting transaction*, or encouraging the other participants in a blockchain network to initiate a *hard-fork*.[281] As explained above, centralised platforms can support reversibility better than distributed platforms.[282] For example, the only way to release the *frozen* Parity funds is reportedly through an Ethereum hard fork.[283] While the

[276] *See id.*

[277] *See id*.

[278] *See* Sklaroff, *supra* note 182, at 277–78.

[279] *See* Werbach & Cornell, *supra* note 250, 369, 374.

[280] *See* Jenny Cieplak & Simon Leefatt, *Smart Contracts: A Smart Way to Automate Performance*, 1 GEO. L. TECH. REV. 414, 418 (2017).

[281] *See* NISTIR OVERVIEW, *supra* note 6, at 33–34.

[282] *See* discussion *supra* Section 3.3.2.

[283] *See* Hern, *supra* note 275.

Parity team has proposed such a *hard fork*,[284] as of March 2018, it appeared unlikely that the rest of the Ethereum participants would agree to one.[285]

[107] It may be possible to incorporate logic for unwinding a transfer into the smart contract at the outset. For instance, enforcement of the contract could, in theory, be structured to allow for arbitration by a third-party adjudicator with their own private key.[286] This would however re-introduce a requirement of trust in a third party and add a further layer of complexity to the code. It is not clear at present who these adjudicators would be or what procedural and substantive rules they would apply in resolving disputes.[287]

[108] As explained in Section 3.3.2 above, centralised platforms can support reversibility better. As a result, with a centralised platform, it should be easier to arrange a corrective fork. The TTP or small group of trusted nodes can agree to correct the ledger.[288]

[284] *See On Classes of Stuck Ether and Potential Solutions*, PARITY TECH (Dec. 11, 2017), https://paritytech.io/blog/on-classes-of-stuck-ether-and-potential-solutions-2.html [https://perma.cc/XE36-4W76].

[285] *See* Rachel Rose O'Leary, *High Stakes: Ethereum's Fight Over Lost Funds Explained*, COINDESK (Feb. 25, 2018, 10:31 PM), https://www.coindesk.com/high-stakes-ethereums-fight-lost-funds-explained/ [https://perma.cc/9XNY-KVSU].

[286] *See* Vitalik Ruterin, *Multisig: The Future of Bitcoin*, BITCOIN MAG. (Mar. 12, 2014), https://bitcoinmagazine.com/11108/multisig-future-bitcoin/ [https://perma.cc/AXJ9-K5JF]; *see also* Werbach & Cornell, *supra* note 250, at 375.

[287] *See* Sklaroff, *supra* note 182, at 300–01.

[288] *See* discussion *supra* Section 3.3.2.

6.1.4 Confidentiality and Trade Secrets

[109] As noted above in Section 5, the code of a smart contract is executed by all nodes on the network and is publicly visible.[289] However, many contracts contain commercially sensitive information.[290] Thus, smart contracts are inappropriate for contracts that contain information that would otherwise be subject to a non-disclosure agreement or confidentiality clause. In a worst-case scenario, revealing information through a smart contract could lead to inadvertent loss of trade secret protection or to a breach of confidentiality. This is less of an issue on centralised platforms, where the TTP or trusted nodes can control visibility of the blockchain.

6.2 Blockchain Data and the GDPR

[110] The application of EU data protection law to blockchain-based platforms raises difficult questions. In this section, we first consider data protection law's applicability, before reviewing who would qualify as controllers or processors and considering compliance and liability.

6.2.1 Will Data Protection Laws Apply?

[111] EU data protection laws apply to the processing of personal data that falls within the regime's territorial scope.[291] The General Data

[289] *See* discussion *supra* Section 5.

[290] *See* David Cerezo Sánchez, *Private and Verifiable Smart Contracts on Blockchains*, CALCTOPIA 2 (May 20, 2018), https://eprint.iacr.org/2017/878.pdf [https://perma.cc/5CSA-ZDLJ].

[291] *See EU General Data Protection Regulation (GDPR)*: Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC, (General Data Protection Regulation), OJ 2016 L 119/1, art. 3 [hereinafter GDPR].

Protection Regulation (GDPR)[292] entered into force in May 2018 and has a broad territorial reach. The GDPR applies to controllers and processors *established* in the EU.[293] Existing case law suggests that the test for establishment will be applied expansively.[294] The GDPR also applies to controllers and processors not established in the EU, where the processing relates to the offering of services to data subjects who are in the EU or monitoring of their behaviour that takes place within the EU.[295]

[112] As a result, the activities of many blockchain operators will fall within the regime's territorial scope. For example, since anybody can use an open/permissionless platform, operators of such platforms may be deemed to offer services to data subjects in the EU. For instance, it could be argued that the nodes and miners who collectively support the Bitcoin network offer a payment service to EU data subjects. In contrast, to avoid the GDPR's applicability, non-EU-established operators of closed/permissioned platforms could attempt to prevent data subjects located in the EU from using their platforms.

[113] *Processing* is broadly defined. It refers to any operation or set of operations performed on personal data.[296] As a result, blockchain users,

[292] *See id.*

[293] *See id.* at art. 3(1).

[294] *See* Google Spain v. Agencia Española de Protección de Datos, C-131/12, § 54–59 (E.C.J. May 13, 2014) [hereinafter Google Spain v. González] (stating the concept of establishment was interpreted so as to provide a broad territorial scope in order to "prevent individuals from being deprived of the protection guaranteed by the directive and that protection from being circumvented . . . .").

[295] *See* GDPR, *supra* note 291, at art. 3(2) (constituting a change from the test in the Data Protection Directive, which focused on use of 'equipment' in the EU rather than offering services to or monitoring the behavior of data subjects in the EU. Both approaches, however, are potentially overly broad in scope); *see also* W. Kuan Hon, Julia Hőrnle & Christopher Millard, *Which Law(s) Apply to Personal Data in Clouds?, in* CLOUD COMPUTING LAW (Christopher Millard ed., 2013).

[296] *See* GDPR, *supra* note 291, art. 4(2).

nodes, and miners may engage in processing of personal data when sending, verifying, and storing transaction data.[297]

[114] The definition of *personal data* is also very expansive. It covers any information that relates to an identifiable person, i.e. a person who can be identified *directly or indirectly.*[298] To determine whether a person can be indirectly identified, account should be taken of all the means likely reasonably to be used by the controller or by any other party to identify the person.[299]

[115] A blockchain database is likely to contain at least two types of data. First, it will store metadata related to transactions, namely the sender's and recipient's addresses and a timestamp.[300] Second, it will store data on the object of a transaction.[301] For instance, in the case of Bitcoin, the object would be an amount of BTC.[302] We will now consider each of these in turn.

i. Metadata as Personal Data

[116] With respect to metadata, if the platform's users are natural persons, the sender's and recipient's addresses may well qualify as personal data. This is most obvious where these addresses directly reveal a person's identity. For specific applications, for example a land registry blockchain, titles to property may be transferred from one named

[297] *See* Michèle Finck, *Blockchains and Data Protection in the European Union*, Research Paper No. 18-01 MAX PLANCK INST. FOR INNOVATION & COMPETITION 1, 9–10, (2018), https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3080322.

[298] *See* GDPR, *supra* note 291, at art. 4(1).

[299] *See id*. at Recital 26.

[300] *See* NISTIR OVERVIEW, *supra* note 6, at 20.

[301] *See id*.

[302] *See id.* at 40.

individual to another. While a platform operator may opt to *pseudonymise* the data, by replacing a person's name with a pseudonym, the GDPR makes it clear that such pseudonymised data will still qualify as personal data.[303]

[117] Even Bitcoin's disposable public keys and addresses may qualify as personal data.[304] The ECJ has determined that information can constitute personal data even where only a third party has the additional data necessary to identify the person.[305] In such cases, whether information is personal data may depend on whether the possibility of combining the two sources is "a means likely reasonably to be used" to identify the data subject.[306]

[118] Although there is no central register matching addresses to individuals, a Bitcoin address might still be linked to a real-world identity by combining it with other data.[307] Intermediaries, such as wallet services or exchanges, may register users' real-world identities, for instance to comply with regulatory requirements.[308] Further, the counter-parties a user transacts with, such as merchants, may register users' real-world identities for their own commercial purposes.[309] Combining intermediary records with the public blockchain would reveal the real-world identity behind a Bitcoin address.

---

[303] *See* GDPR, *supra* note 291, at Recital 26.

[304] *See* Finck, *supra* note 297, at 13–14.

[305] *See* Breyer v. Germany, C-582/14, § 31, 39 (E.C.J. 2016).

[306] *See id.* at § 45.

[307] *See* Reid & Harrigan, *supra* note 215, at 211.

[308] *See* Ana Alexandre, *US: Cryptocurrency Trading Platforms Must Be Registered with SEC*, COINTELEGRAPH (Mar. 7, 2018), https://cointelegraph.com/news/us-cryptocurrency-trading-platforms-must-be-registered-with-sec [https://perma.cc/FF86-JVM3].

[309] *See* Reid & Harrigan, *supra* note 215, at 201.

[119] In addition, as noted in Section 4.2 above, it may be possible to determine Bitcoin user identities by other methods, such as linking public keys to IP addresses.[310] Finally, metadata may reveal a pattern of transactions with publicly known addresses (such as merchants) that could be used to single out an individual user, such as through a technique known as *transaction graph analysis*.[311] For example, if a certain restaurant accepts Bitcoin as payment and its address is publicly known, then payments to that address would suggest that the sender visited that restaurant at a certain time.[312] Given this, Bitcoin addresses and public keys might in certain circumstances qualify as personal data.

[120] Conversely, if a platform's users are all legal persons, such as businesses, the platform could be designed such that the metadata does not contain information related to natural persons. For example, a group of banks could set up a closed/permissioned platform to settle end-of-day inter-bank payments for their own accounts, i.e. reflecting the sum total of individual transactions at the inter-bank level. In this case, the addresses might refer only to the sending and receiving banks in question and need not relate to any identifiable person.

ii. Object of Transactions Data as Personal Data

[121] With respect to the object of transactions, in many use cases, this information will not relate to an identifiable person. For instance, in Bitcoin, the amount of BTC transferred does not necessarily relate to an identifiable person,[313] nor would payment data for an overall end-of-day settlement between banks.

---

[310] *See* Biryukov et al., *supra* note 217, at 15.

[311] *See* Adam Ludwin, *How Anonymous Is Bitcoin?*, COIN CTR. (Jan. 20, 2015), https://coincenter.org/entry/how-anonymous-is-bitcoin [https://perma.cc/4RTP-AMJY].

[312] *See id.*

[313] In some cases, the amount paid could be combined with information about the recipient address to specify the product or service paid for, which may help 'single out' the sender.

[122] Nonetheless, in other use cases, the object of the transaction could be linked to real-world identities. For example, a group of retail banks could set up a blockchain platform to share KYC (Know Your Customer) information on their customers with each other. In that case, the object of transactions would be information about natural persons and could be written into the blockchain.

[123] However, it may be possible to design a blockchain platform such that any personal data is not stored *on the chain*, but is stored in encrypted form in a separate, *off-chain* database.[314] The blockchain transaction data would then only contain the information needed to access the personal data in the separate database.[315] In this manner, it may be possible to confine personal data to the off-chain storage and avoid storing such data on the blockchain.

6.2.2 Who Will be Subject to Legal Obligations as Controller(s) and Processor(s)?

[124] Data controllers and processors are responsible for ensuring compliance with data protection law. The controller is the natural or legal person who determines the purposes and means of processing personal data.[316] The ECJ has held that *controller* should be interpreted broadly, so as to ensure the effective and complete protection of data subjects.[317] A processor is any natural or legal person who processes personal data on behalf of the controller.[318]

---

[314] *See* Finck, *supra* note 297, at 11–12.

[315] *See* Guy Zyskind et al., *Decentralizing Privacy: Using Blockchain to Protect Personal Data*, IEEE SECURITY PRIVACY WORKSHOPS (2015).

[316] *See* GDPR, *supra* note 291, at art. 4(7).

[317] *See* Google Spain v. Agencia Española de Protección de Datos, C-131/12, § 34–38 (E.C.J. May 13, 2014).

[318] *See* GDPR, *supra* note 291, at art. 4(8).

[125] As noted above, the personal data stored on a blockchain may consist of metadata and data on the object of each transaction.[319] The *purposes and means* of processing this personal data can be analysed from two perspectives. On the one hand, at the macro-level, looking at the blockchain infrastructure as a whole, the purpose of processing personal data is to provide the associated service. For instance, with regard to Bitcoin, the purpose of processing transaction data is to provide a peer-to-peer system of electronic cash.[320] At this level, the 'means' of processing will generally consist of (i) the software that nodes and miners run to find new blocks and store and update the blockchain database, and (ii) the hardware that nodes and miners use for this purpose.

[126] From this macro-level perspective, nodes and miners arguably decide to engage in processing for their own *purposes*, namely to facilitate the platform. They would also determine the *means* of processing, by deciding which software and hardware to use.

[127] On the other hand, at the micro-level, looking at individual transactions, the *purpose* of the processing is to record a specific transaction onto a blockchain.[321] At this level, the *means* would refer to the choice of blockchain platform.

[128] From this micro-level perspective, users enter personal data into the system when submitting their transactions.[322] Thus, for each specific item of personal data, the individual user arguably determines the *purposes* of processing, namely: to record a specific transaction onto the blockchain. The user also determines the *means*, namely: to use that blockchain platform to execute their transaction. From this perspective,

[319] *See* discussion *supra* Section 6.2.1.

[320] *See* Nakamoto, *supra* note 34, at 1.

[321] *See id.*

[322] *See id.* at 6.

nodes and miners simply facilitate access to a blockchain database, while the users determine which data are stored there.

[129] In many cases, the analysis of who *determines the purposes and means of processing* will depend on whether you adopt the macro- or micro-level perspective. Since data protection law is concerned with the processing of specific items of personal data, we consider the micro-level perspective more appropriate. To illustrate this point, we consider three different use cases below.

i. Centralised Platform: Land Registry

[130] With a centralised platform, the platform operator will be likely to determine the *means* of processing at the macro-level. For instance, with a land registry, the government agency setting up the platform could either develop the underlying software in-house, or buy in software from a third-party developer. The agency could then run a single node and miner, acting as a TTP. Similarly, at the macro-level, the agency would decide to process personal data on a blockchain platform for the purpose of providing a registry of titles to land. Seen from the macro-level, one could argue that the land registry should be considered a controller.

[131] However, the micro-level perspective instead focuses on individual transactions. The personal data processed on a land registry blockchain would be metadata: in this case, the sender and recipient's identifiers. Users enter this personal data onto the platform for their own purposes, namely to register and/or transfer titles to land. Users also arguably determine the means of processing by choosing the blockchain-based land registry as the medium to execute their transfers. Once users have submitted transactions, the government agency may merely process associated data on the users' behalf. Seen from this micro-level perspective, the user should arguably be considered the data controller, with the agency acting only as a processor on their instructions.

[132] In practice, the government agency need not perform the processing itself, but may engage a sub-processor. For instance, it might

use a Blockchain-as-a-Service (BaaS) offering, whereby a third party provides the underlying supporting infrastructure. The agency could pay a third party to run the miner and node on the third-party's own hardware. In such cases, the BaaS-provider could qualify as a sub-processor when processing personal data for the land registry.

[133] It is important to note, however, that there may be multiple data controllers in relation to a particular set (or subset) of personal data. For example, even if we categorise the government agency running the blockchain land registry platform as a *mere processor* for the purpose of individual transactions, it may nevertheless be a controller for other purposes such as assessment and collection of taxes relating to land transactions.

ii. Closed, Permissioned Platform: Inter-Bank Customer Data Sharing

[134] As a second example, assume a group of parties decide to set up a closed, permissioned blockchain platform with a small number of trusted nodes. For instance, a group of retail banks may set up a blockchain to share information on their customers for KYC purposes. The platform is closed (only the founding banks, or others they authorise, can use it) and private (only the participating banks can view the blockchain database).

[135] At the macro-level, the parties who set up the platform would determine the means of processing by designing the platform. Thus, in specifying the software, the banks would determine which data to store on the blockchain and how it is processed through the consensus protocol. They could also dedicate resources to running the nodes. The banks also arguably determine the purpose of processing, namely to share KYC information. Seen from this perspective, the banks could be characterised as controllers when setting up the platform and when acting as nodes and miners.

[136] However, as above, the micro-level perspective would instead focus on individual transactions. In this case, the personal data would be

the object of the transactions (namely: the customer records). Banks enter this information onto the platform when submitting transactions. In line with the above analysis, as users, each bank would arguably act as a controller with regard to the customer data it submits to the platform. Further, when processing the data as nodes and miners, the banks might be acting only as processors with regard to the customer data that other participating banks have submitted.

[137] The above applies so long as the group of banks acting as nodes/miners only process the transaction data for the purposes determined by the sending user (namely to execute the transaction). If they engage in further processing of the data for their own purposes, they would likely become controllers of that data.[323] For example, a bank could analyse the customer data stored on its copy of the blockchain to glean commercial insights.

iii. Open, Distributed Platform: Cryptocurrency

[138] For open, distributed platforms, such as Bitcoin, determining controllers and processors is difficult.[324] The definition used by data protection law is arguably ill-suited to distributed platforms, which purposefully lack a central administrator who could bear responsibility for compliance.[325] Instead, control is deliberately distributed.

[139] At the macro-level, the platform's purpose is to facilitate a peer-to-peer system of electronic cash.[326] The means consist of the Bitcoin core software and the hardware provided by nodes and miners. It is generally accepted that these purposes and means were originally envisaged by a

[323] *See* Article 29 Data Protection Working Party, Opinion 05/2012 on Cloud Computing, 8, 01037/12/EN WP 196 (2012) [hereinafter Cloud Computing].

[324] *See* Finck, *supra* note 297, at 16-18.

[325] *See id*.

[326] *See* Nakamoto, *supra* note 34, at 1.

person (or persons) known as "Satoshi Nakamoto."[327] Today, the Bitcoin core code developers control the core software (see Section 3.3 above).[328] This arguably gives them a high degree of factual control over the *why* and *how* of processing Bitcoin transaction data.[329] However, the developers do not process any personal data themselves, unless they also happen to run nodes or mine new blocks.[330] They merely make the software available for others to use.[331] As a result, they are unlikely to qualify as either controllers or processors under data protection law.

[140] Nodes and miners process personal data in the form of Bitcoin addresses, for instance when they store and broadcast transaction data.[332] They decide to process such data for the purposes of facilitating the cryptocurrency and, in the case of miners, to reap a reward for mining new blocks.[333] They provide means in the form of hardware and do so on their own behalf, rather than on instructions from any other party. Given this, the miners and nodes arguably could be controllers.

[141] However, they have limited factual influence over the 'why' and 'how' of processing. Nodes and miners cannot easily (if at all) change the

[327] *See* Mitchell Hyman, *Bitcoin ATM: A Criminal's Laundromat for Cleaning Money*, 27 ST. THOMAS L. REV. 296, 298 (2015).

[328] *See* Christopher, *supra* note 164, at 150.

[329] *See* Article 29 Working Party, Opinion 1/2010 on the Concepts of "Controller" and "Processor," 11, 14, 00264/10/EN WP169 (Feb. 16, 2010) [hereinafter Controller and Processor].

[330] *See* Jeffery Atik & George Gerro, *Hard Forks on The Bitcoin Blockchain: Reversible Exit, Continuing Voice*, 1 STAN. J. BLOCKCHAIN L. & POL. 1, 5 (2018).

[331] *See* NISTIR OVERVIEW, *supra* note 6, at 44–45.

[332] *See* discussion *supra* Section 3.1, 6.2.1.

[333] *See* discussion *supra* in Section 3.1.

'core' software and its consensus protocol.[334] At most, they can propose changes or move to a different fork.[335] Instead, they download the software and run it passively on their computers.[336] Given this distribution of control, it is not straightforward to identify controllers at the macro-level.

[142] As above, the micro-level perspective focuses instead on individual transactions. The personal data in this case are the sender and recipient's Bitcoin addresses and (potentially) the related transaction data (e.g. timestamp and amount of BTC). Thus, with respect to each item of personal data, the sending user decides to submit it to the Bitcoin platform for their own purpose, namely to transfer a certain quantity of value to the recipient. In addition, they arguably determine the means of processing, by deciding to use Bitcoin for their transaction. Seen from this micro-level perspective, the users should be considered data controllers. Nodes and miners may simply process this data on behalf of each user.

[143] One could argue that the users have even less factual influence over the means of processing, since they cannot change the Bitcoin software that nodes and miners run.[337] However, this imbalance in power over the means of processing applies to other cases involving individual users and large service providers. For instance, with cloud services, a customer can often only use a commoditised cloud service without modification and may have no choice but to accept the standard contractual terms offered by a large cloud service provider if they wish to use a particular service.[338] Nonetheless, as controllers, the customers

[334] *See* discussion *supra* in Section 3.3; *see also* Finck, *supra* note 297, at 17.

[335] *See* discussion *supra* in Section 3.3.

[336] *See* discussion *supra* in Section 3.3.

[337] *See* discussion *supra* in Section 3.3.

[338] *See* Simon Bradshaw, Christopher Millard, Ian Walden, *Standard Contracts for Cloud Services, in* CLOUD COMPUTING L. (Christopher Millard ed., 2013).

remain responsible for their decision to use a certain service. They should choose a cloud provider that guarantees compliance with the relevant requirements of data protection law.[339] Similarly, cryptocurrency users should arguably choose a platform that is compliant with data protection law.

[144] Nonetheless, some users may benefit from an exemption for personal activities. EU data protection law does not apply to natural persons in the course of a purely personal or household activity.[340] Thus, if a group of friends use a cryptocurrency like Bitcoin to make payments to each other, they may be exempt from data protection law in relation to such processing. However, if a user makes payments outside of a personal or household activity, such as for commercial, political, or charitable purposes, the exemption may not apply.[341] Further, the exemption would be unlikely to apply to legal persons who make Bitcoin payments. In such circumstances, users will typically be subject to the full responsibilities of a data controller, as set out in Section 6.2.3 below.

[145] Finally, anybody who accesses the data stored on a public blockchain and processes it for their own purposes becomes a data controller. Thus, if a node analyses the payments data in its local copy of the blockchain to glean commercial insights, it would become a controller in respect of any personal data involved.

iv. Conclusions Regarding Data Controllers and Processors

[146] In each of the above examples, the characterisation of participants as controllers and/or processors depends on whether a blockchain use case is analysed from the macro- or micro-level perspective. Given that data protection law is concerned with the processing of specific items of

[339] *See* Cloud Computing, *supra* note 323, at 8.

[340] GDPR, *supra* note 291, at art. 2(2)(c).

[341] *See* Cloud Computing, *supra* note 323, at 8, 10.

personal data, the micro-level perspective is arguably a more appropriate starting place. Following this line of reasoning, users would be considered data controllers in respect of the personal data they submit to the blockchain platform, since they determine both purposes (to execute the transaction) and means (in choosing the platform). They delegate decisions on the technical and organisational details of the processing to the collective of developers, nodes, and miners.

[147] Whether nodes and miners should also be deemed controllers would depend on the facts of each case. If nodes and miners merely process transaction data on behalf of users, they might merely be processors, rather than controllers. In some cases, they may simply facilitate the processing of transactions on behalf of users, by passively running the relevant software. In this respect, they could be compared to providers of cloud computing services. Cloud providers offer Internet-based, flexible, location-independent access to computing resources, including processing capability and storage.[342] In many cases, the cloud customer acts as the data controller, with the cloud provider merely processing the data on their behalf.[343] Similarly, a blockchain-based platform provides access to a distributed application for processing and storing transaction records.[344] Just like cloud providers, nodes and miners who provide users with access to hardware and applications are likely to be processors with regard to the personal data submitted by users.[345]

[148] If, however, nodes and miners take a more active role with regard to the transaction data, they may also be deemed to be controllers. In that case, nodes and miners could be compared to SWIFT, a financial messaging service that facilitates international money transfers for

[342] *See* W. Kuan Hon & Christopher Millard, *Cloud Technologies and Services*, *in* CLOUD COMPUTING L. (Christopher Millard ed., 2013).

[343] *See* Cloud Computing, *supra* note 323, at 7–8.

[344] *See* Singh & Michels, *supra* note 190, at 3–4.

[345] *See generally* Hon et al., *supra* note 295.

financial institutions.[346] In doing so, SWIFT processes personal data such as the names of payers and payees.[347] SWIFT initially presented itself as a mere processor, relaying messages on behalf of the financial institutions. However, the Article 29 Working Party determined that SWIFT should be considered a controller, since it acted with a significant level of autonomy in relation to the personal data it processed, including by developing, marketing, and changing the services it offered, deciding to establish a data centre in the US and to disclose data to the US Treasury.[348] Thus, the more autonomy and *effective margin of manoeuvre* the nodes and miners have in respect of the personal data they process, the more likely they are to be considered controllers.

6.2.3 Can Blockchain Controllers and Processors Comply with Data Protection Law?

[149] The uncertainty around the status and roles of controllers and processors complicates many aspects of data protection compliance, including in particular the following:

i. Lawful Grounds for Processing

[150] First, controllers need a lawful ground for processing personal data.[349] Processors do not need to establish independently that the controller has valid grounds for processing.[350]

---

[346] *See* Article 29 Data Protection Working Party, Opinion 10/2006 on the Processing of Personal Data by the Society for Worldwide Interbank Financial Telecommunication (SWIFT) 01935/06/EN WP128, 2 (2006) [hereinafter SWIFT].

[347] *See id.*

[348] *Id.* at 11.

[349] GDPR, *supra* note 291, at art. 6. (listing of several grounds including, *inter alia,* (i) data subject consent; or that processing is necessary for compliance with (ii) a contract to which the data subject is party; (iii) the controller's legal obligation; or (iv) for legitimate interests the controller is pursuing, provided that the controller's interests are not "overridden by the interests, fundamental rights and freedoms of the data subject").

[151] We argue above that users of blockchain platforms are likely to be deemed controllers. Consequently, unless covered by the household exemption (or another exemption),[351] each user will need to be able to demonstrate one or more lawful grounds for processing the personal data they submit to the blockchain. For instance, in the above banking example, each bank will need to determine whether its existing grounds for processing customer data extend to processing by means of a private, permissioned blockchain. Further, users of distributed, public platforms such as Bitcoin need to have a legal basis for processing the recipient's address (unless they are covered by the household exemption).[352] It could be argued that, in signing up for a Bitcoin address, a recipient has implicitly consented to the processing of that address for transaction purposes.

[152] Conversely, we argue that miners and nodes may be deemed *mere processors*, provided they don't also process personal data for their own purposes (for which they would then need a justification). As a result, they would not normally need to verify whether the controller has valid grounds for processing.

ii. Controller and Processor Obligations

[153] Second, joint controllers must determine their respective responsibilities for compliance by means of an arrangement between them.[353] Further, controllers must put in place a contract with processors

[350] *See id.* at art. 28 (3). That said, if, in their opinion, the instructions they receive from controllers infringe the GDPR, processors may be under an obligation to inform the controller accordingly.

[351] *E.g.*, *id.* at arts. 85, 89.

[352] *See*, *id.* at arts. 6, 85, 89.

[353] *See id.* at art. 26.

to determine how personal data will be processed, including the subject-matter, duration, nature, and purpose of the processing.[354]

[154] Thus, for each platform, the (joint) controller(s) and processor(s) must establish contractually their data protection responsibilities amongst themselves. Achieving this should generally be easier with closed, centralised platforms, since fewer parties are involved as nodes and miners, making it easier to coordinate compliance. For instance, in the above banking example, the banks would need to establish their respective responsibilities by means of a contract. Similarly, the land registry would need to establish its legal responsibilities as a processor via contracts with the users of its platform. It would probably seek to do so by requiring users to agree to terms of service before accessing the platform.

[155] For open, distributed platforms, it is unclear how controllers and processors might comply with these obligations. In theory, large numbers of users, nodes, and miners would need to enter into detailed contracts in order to establish their responsibilities. In practice, the most feasible way to achieve this may be through standard-form terms and conditions to be agreed whenever a user, node, or miner first uses a platform. These terms would set out the parties' legal obligations.

[156] However, this raises the question as to who will draw up the terms and conditions. As noted above in Section 3.3.1, the platform's software developers are the only closed, centralised layer in Bitcoin (as is the Ethereum Foundation for Ethereum).[355] As a result, they are best-positioned to coordinate compliance by designing the platform such that only those who accept the relevant terms and conditions are able to join it. However, as argued above in Section 6.2.2, developers are not controllers or processors in relation to transaction data and are therefore not subject to the contractual requirements of the GDPR. Nonetheless, developers have

[354] *See* GDPR, *supra* note 291, at art. 28.

[355] *See* Christopher, *supra* note 164, at 150.

an interest in promoting their platform and may find that designing it to enable compliance attracts more miners, nodes, and users.

[157] Thus, software developers could require nodes and miners to agree to contractual terms when downloading or updating the relevant software. For example, the Ethereum website contains standard-form terms and conditions governing the use of its software platform, the Bitcoin Core website does not.[356] That said, Ethereum's terms do not cover data protection compliance.[357] Further, users would need to agree to contractual terms when joining the service through the user interface. However, this is difficult for Bitcoin and Ethereum, since users need not interact with the software directly.[358] Instead, user-facing intermediaries (such as wallets and exchanges) would need to require users to agree to a platform's terms and conditions during sign-up.

[158] In addition, the GDPR imposes conditions on transfers of personal data from the EU to *third countries*, i.e. any country outside the EEA.[359] Thus, controllers must ensure they have an appropriate legal basis for any international data transfer to a third country. Returning to our earlier examples, in order to run a node in a third country, the land registry and banks would need to ensure an adequate level of protection or appropriate safeguards (for instance by locating the node in a country subject to a Commission adequacy decision or by putting in place adequate safeguards such as via approved standard contract clauses).

---

[356] *Compare Legal Agreement*, ETHEREUM, https://www.ethereum.org/agreement [https://perma.cc/73LT-UMXL], *with About*, BITCOINCORE, https://bitcoincore.org/en/about/ [https://perma.cc/6NDB-XV4F].

[357] *See Legal Agreement*, ETHEREUM, https://www.ethereum.org/agreement [https://perma.cc/3L4D-93W4].

[358] *See* Kevin D. Werbach, *Trust, But Verify: Why the Blockchain Needs the Law*, BERKELEY TECH. L.J. (forthcoming 2018) (manuscript at 27).

[359] *See* Hon et al., *supra* note 295. *See generally* GDPR, *supra* note 291, at ch. V.

[159] However, open, distributed platforms are by design unconstrained by international borders: typically anybody, anywhere, can download the entire transaction archive and start processing new transactions as a node or miner.[360] As a result, use of these platforms is likely to entail data transfers to third countries. Since any party in any third country can download the archive, adequacy decisions and appropriate safeguards (including binding corporate rules) are unlikely to provide sufficient coverage. Since implicit consent does not suffice for international transfers, the platform's terms of use would need to provide for explicit user consent.[361]

iii. Data Subject Rights

[160] Third, data subjects have rights in respect of their personal data. These include a right to rectification of inaccurate personal data and to data erasure (also known as the *right to be forgotten*).[362] At first glance, these rights appear to run counter to blockchain technology's 'immutability'. However, the ability to comply with such requests differs, depending on the design of the blockchain platform.

[161] Centralised platforms can support reversibility better and can limit visibility of a record to certain parties (see Sections 0 and 0 above).[363] As a result, they would be in a better position to comply with data subjects' requests to rectify or erase data in past blocks. For example, if a user requested the banks to rectify a specific piece of information in their customer record on the blockchain, each bank could comply by altering the relevant transaction record and re-hashing the subsequent blocks in

[360] *See* Finck, *supra* note 297, at 18–19.

[361] *See* GDPR, *supra* note 291, at art. 49 (1)(a) (indicating "explicit consent" as one of various "derogations" from the data transfer restrictions).

[362] *See id.* at arts. 16–17.

[363] *See* Buterin, *Public and Private Blockchain*, *supra* note 138.

their copy of the ledger. Operators of centralised platforms should similarly be able to comply with requests for erasure.

[162] For open, distributed platforms, it is unclear how individual participants at the user, node or miner level would comply with such requests. A node can only alter its own local copy of the ledger.[364] Thus, even if all users, nodes, and miners were considered controllers, this would not necessarily provide effective protection for data subjects.[365] In theory, all nodes could agree by contract to 'fork' to a new version of the blockchain periodically, to reflect requests for rectification or erasure. However, in practice, this level of coordination may be difficult to achieve among potentially thousands of nodes.

[163] Beyond altering the chain, there may also be other technical approaches to assist data protection compliance. For instance, a blockchain application might not require storage of personal data on-chain, but rather provide links to such data residing externally.[366] Therefore, implementing mechanisms that allow deletion of data (despite a link persisting on a block) may be enough to satisfy a request for erasure; so too might deleting all instances of a private key for encrypted data (be it stored on- or off-chain), so as to make that data inaccessible. Technical approaches targeting data protection issues are an active area of research and they are likely to receive an additional impetus due to legal obligations to demonstrate *data protection by design*.[367]

[364] *See* discussion *supra* Section 3.1.

[365] *See* Matthias Berberich & Malgorzata Steiner, *Blockchain Technology and the GDPR—How to Reconcile Privacy and Distributed Ledgers?*, 2 EUR. DATA PROT. L. REV. 424, 426 (2016).

[366] *See* Guy Zyskind, et al., *Decentralizing Privacy: Using Blockchain to Protect Personal Data*, 2015 IEEE SEC. & PRIVACY WORKSHOPS 180, 181 (2015).

[367] *See* GDPR, *supra* note 291, at art. 25.

iv. Liability

[164] This preliminary analysis illustrates the significant uncertainty as to how EU data protection law might apply to blockchain applications and in particular to open, distributed blockchain platforms. Given the potential severity of penalties under the GDPR, there is a risk that this legal uncertainty will have a chilling effect on innovation, at least in the EU and potentially more broadly. For example, if all nodes and miners of a platform were to be deemed joint controllers, they would have joint and several liability, with potential penalties under the GDPR of up to EUR 20 million or 4% of global turnover/revenues, whichever is higher.[368]

[165] As a result, it might be helpful if the Article 29 Working Party, or its successor body under GDPR, the European Data Protection Board, were to issue guidance regarding the application of data protection law to various common blockchain models. At a national level, as part of its Information Rights Strategic Plan 2017-2021, the UK Information Commissioner's Office has launched a programme to fund research into the privacy implications of various new technologies, including blockchain.[369]

6.3 Initial Coin Offerings and Securities Law

[166] An initial coin offering (ICO)—or *token sale*—is a way for a start-up with a new blockchain-based service to raise money by selling an initial set of tokens.[370] The company then uses the money raised to launch the service.[371] Purchasers of the coins or *tokens* can then *spend* their

[368] *See id.* at art. 83.

[369] *See Grants Programme 2018*, INFO. COMMISSIONER'S OFF. (2018), https://ico.org.uk/about-the-ico/what-we-do/grants-programme-2018/ [https://perma.cc/VLQ4-YMHA].

[370] *See* Jin Enyi & Ngoc Dang Yen Le, *Regulating Initial Coin Offerings ("Crypto-Crowdfunding")*, 8 J. INT'L BANKING & FIN. L. 495 (2017).

[371] *See id.*

tokens to access the service or sell them on cryptocurrency exchanges.[372] Many ICO-tokens are built through smart contracts on top of the Ethereum blockchain. ICOs raised an estimated U.S. $5.5 billion in 2017.[373]

[167] Purchasing tokens in an ICO is a high-risk activity.[374] Many companies offering ICOs provide investors with little more than a whitepaper and a website.[375] If the service proves popular, the tokens' value can increase dramatically. Conversely, if the start-up fails to launch a valuable service, the tokens may become worthless, leaving investors with losses. For example, the terms of the Status ICO, which raised over U.S. $100 million in 2017, noted that the development of the Status project may be abandoned for lack of interest from the public, lack of funding, or lack of commercial success.[376] The recent management battle at Tezos, which raised U.S. $232 million through an ICO in 2017, further illustrates the risk of such early stage investment.[377]

[168] From a regulatory perspective, the details of the offering are important, particularly the rights associated with the token. Some token

[372] *See* Nathaniel Popper, *An Explanation of Initial Coin Offerings*, N.Y. TIMES (Oct. 27, 2018), https://www.nytimes.com/2017/10/27/technology/what-is-an-initial-coin-offering.html [https://perma.cc/22QG-5XYK].

[373] McLannahan, *supra* note 2.

[374] *See* Popper, *supra* note 372.

[375] *See Initial Coin Offerings: Know Before You Invest*, FIN. INDUSTRY REG. AUTHORITY (Aug. 31, 2017), http://www.finra.org/investors/alerts/initial-coin-offerings-know-before-you-invest [https://perma.cc/U4GT-G69Y].

[376] *SNT Creation and Status Project Creation Conditions: Explanatory Note & Governance Terms*, STATUS, https://contribute.status.im/status-terms.pdf [https://perma.cc/M5V5-27H9] (referring to § 5, "Risk of abandonment / lack of success").

[377] *See* Maria Terekhova, *What Tezos Crisis Could Mean for the ICO Space*, BUS. INSIDER (Oct. 26, 2017, 9:06 AM), https://www.businessinsider.com/what-tezos-crisis-could-mean-for-the-ico-space-2017-10?r=UK&IR=T [https://perma.cc/47HQ-JN7Y].

sales may offer investors the opportunity to profit from a company's success by promising them a share of the resulting profits.[378] Hacker and Thomale refer to such tokens as *investment tokens*.[379] Investment token sales resemble more traditional sales of securities, like Initial Public Offerings (IPOs).[380] Unlike IPO investors, however, ICO investors typically do not gain equity in the company and may have very limited ability to influence the company's direction.[381]

[169] In other instances, token sales offer investors the opportunity to use the service once it's launched.[382] Hacker and Thomale classify such tokens as *utility tokens*.[383] In such cases, the offer of tokens might appear closer to a pre-launch 'sales' arrangement, similar to other crowdfunding arrangements such as Kickstarter.[384] The characterisation of tokens is important, since many jurisdictions seek to protect investors by regulating securities.[385] A key means of providing protection is to mandate disclosure by filing a prospectus, so that investors have access to the information

[378] *See* Phillip Hacker & Chris Thomale, *Crypto-Securities Regulation: ICOs, Token Sales and Cryptocurrencies Under EU Financial Law*, EUR. COMPANY & FIN. L. REV. (Nov. 22, 2017) (forthcoming) (manuscript at 25), https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3075820## [https://perma.cc/98D4-FFS6].

[379] *Id.* manuscript at 13.

[380] Philipp Maume & Mathias Fromberger, *Regulation of Initial Coin Offerings: Reconciling U.S. and E.U. Securities Laws*, CHI. J. INT'L L. (June 15, 2018) (forthcoming) (manuscript at 4), https://papers.ssrn.com/sol3/papers.cfm?abstractid=3200037 [https://perma.cc/WQ7N-R8FJ].

[381] Hacker & Thomale, *supra* note 378, manuscript at 11.

[382] *See id.* at 12.

[383] *Id.*

[384] *See* Enyi & Le, *supra* note 370.

[385] *See* Hacker & Thomale, *supra* note 378, manuscript at 14.

they need in order to assess the risk associated with an investment.[386] This can help to address the informational asymmetry between potential investors and the investment's promoters.[387]

[170] The difficulty lies in the fact that ICOs often combine elements of investment and utility tokens. While the tokens can be used to access the service, ICOs may also offer investors the opportunity to profit from a company's success by selling tokens at a profit on secondary markets.[388]

[171] Regulators have begun to take action in relation to ICOs.[389] Whether a particular ICO will be deemed a security may differ per jurisdiction.[390] In the US, organisers of an ICO will need to register a prospectus with the Securities and Exchange Commission (SEC) if the ICO qualifies as an 'investment contract' under the so-called Howey Test.[391] Under this four-step test, an ICO will qualify as an investment contract if it consists of: (i) an investment of money, (ii) into a common enterprise, (iii) with the reasonable expectation of profits (iv) derived from the entrepreneurial or managerial efforts of others.[392]

---

[386] *See id.*

[387] *See* Werbach, *supra* note 71, manuscript at 29.

[388] *See* Hacker & Thomale, *supra* note 378, manuscript at 13; Jay Clayton, SEC Chairman, *Statement on Cryptocurrencies and Initial Coin Offerings* (Dec. 11, 2017), https://www.sec.gov/news/public-statement/statement-clayton-2017-12-11 [https://perma.cc/7BAE-7QGT].

[389] *See, e.g.*, Hacker & Thomale, *supra* note 378, manuscript at 5–6; *see also* Clayton, *supra* note 390.

[390] *See* Hacker & Thomale, *supra* note 378, manuscript at 6–7.

[391] *See* SEC v. W.J. Howey Co., 328 U.S. 293, 301 (1946); *see also* Hacker, & Thomale *supra* note 380, manuscript at 17–18.

[392] *See W.J. Howey Co.*, 328 U.S. at 301; *see also* Hacker, & Thomale *supra* note 378, manuscript at 18.

[172] The SEC applied this test to two ICOs in July and December 2017. It determined that ICO tokens can qualify as securities, depending on the facts of the case.[393] In the specific case of *The DAO* (as set out in Section 6.6), the SEC deemed the tokens securities and found that their unregistered sale violated securities regulations.[394] In this respect, the SEC considered that *The DAO*'s promotional materials and communications gave investors the reasonable expectation of profits through a return on investment from projects that *The DAO* funded.[395]

[173] Similarly, in the case of Munchee Inc., the SEC ordered the company to cease its token sale since it violated securities law, noting (inter alia) that token purchasers had a reasonable expectation of profits from their investment in the Munchee enterprise.[396] In this respect, the SEC reviewed Munchee's marketing materials including its White Paper, website, a blog post, and statements on a podcast and in various social media.[397] It concluded that although Munchee did not offer a dividend or other periodic payment, its communications raised reasonable expectations that purchasers could profit from the appreciation of value of tokens resulting from Munchee's efforts to develop its business.[398]

[393] *See* Report of Investigation Pursuant to Section 21(a) of the Securities Exchange Act of 1934: The DAO, Exchange Act Release No. 81207 (July 25, 2017) [hereinafter DAO Report]; *see also* Order Instituting Cease-and-Desist Proceedings Pursuant to Section 8A of the Securities Act of 1933, Making Findings, and Imposing a Cease-and-Desist Order, Release No. 10445 (Dec. 11, 2017) [hereinafter Munchee Order].

[394] *See* DAO report, *supra* note 393, at 1–2.

[395] *See id.* at 11–12.

[396] *See* Munchee Order, *supra* note 393, at 1, 6.

[397] *See id.* at 3.

[398] *See id.* at 9.

[174] The UK Financial Conduct Authority has also announced that ICOs would, under certain circumstances, be regulated as securities.[399] Under EU law, organisers of an ICO will need to register a prospectus if the ICO qualifies as a security. Failure to do so can give rise to significant civil and criminal liability.[400] Under the EU Prospectus Regulation,[401] an ICO will qualify as a security if the issued units are (i) transferable, (ii) negotiable, (iii) standardised (meaning they must be easily traded on a capital market), and (iv) functionally similar to shares, bonds, or other forms of securitized debt.[402] Hacker and Thomale argue that under this test, ICOs should be considered securities if the organisers' promotional materials and other communications raise investor expectations of profits.[403] This could be the case, for example, if these materials highlight the possibility of trading tokens on secondary markets.[404] Conversely, a pure *utility token* that is focused only on token-holders' claims to redeem a service from the issuer (and that does not raise expectations of profits) might not be subject to security regulation.[405]

[175] It remains to be seen how EU regulators and courts will approach ICOs. Ultimately, regulators will need to consider how to regulate ICOs in

[399] *See Initial Coin Offerings,* FIN. CONDUCT AUTHORITY (Dec. 9, 2017), https://www.fca.org.uk/news/statements/initial-coin-offerings [https://perma.cc/WRU3-9DS7].

[400] *See* Hacker & Thomale, *supra* note 378, manuscript at 19.

[401] *See generally* Commission Regulation 2017/1129, 2017 O.J. (L168/12) (EU) (describing the regulation when securities are offered to the public or admitted to trading on a regular market).

[402] *See* Hacker & Thomale, *supra* note 378, manuscript at 20–25.

[403] *See id.* at 44 (stating that regulatory laws should apply to currency and utility tokens); *see also* DAO Report, *supra* note 393, at 11–12; Munchee Order, *supra* note 393.

[404] *See* Hacker & Thomale, *supra* note 378, manuscript at 33.

[405] *See id.* manuscript at 28–30.

order to protect investors without chilling innovation.[406] In the long-term, appropriate regulation should bolster these new ways of fundraising. Without protection, investors risk being misinformed and suffering losses, which in turn is likely to undermine confidence in the market as a whole.[407]

6.4 Digital Tokens and Property Law

[176] Blockchains track transactions in digital tokens between users. As noted above in Section 2.2, users exercise control over their tokens through their private keys. Although tokens often have financial value, it is not clear to what extent they qualify as *property* under the law. This section considers the status of blockchain tokens under the property law of England and Wales.[408]

[177] The answer may have significant practical implications. For example, crypto-currency holdings have given rise to disputes in divorce cases, where a court can order the transfer or sale of a party's property.[409] The property status of tokens will likely prove relevant to other legal areas that use definitions of property as well, including the law of torts (e.g. the

[406] *See* Peter Van Valkenburgh, *Framework for Securities Regulation of Cryptocurrencies*, COIN CTR. REP. 59–60 (Aug. 10, 2018), https://coincenter.org/entry/framework-for-securities-regulation-of-cryptocurrencies [https://perma.cc/Z3Y5-ZZ2N].

[407] *See* Werbach, *supra* note 71, manuscript at 30.

[408] Since property law is not harmonised at the EU level, we have chosen to analyse this question under a national law.

[409] *See* Matrimonial Causes Act, 1973, c. 18, pt. 2, §§ 24(1), 25(2)(a) (Eng. & Wales). *See generally* Muhammad Sarfaraz, *Bitcoin, Ripple and Other Cryptocurrency Assets Are Now Part of Divorce Settlements*, LINKEDIN (Feb. 15, 2018), https://www.linkedin.com/pulse/bitcoin-ripple-other-cryptocurrency-assets-now-part-divorce-muhammad/ [https://perma.cc/9UTD-322J] (stating that cryptocurrencies are a significant part in divorce settlements).

tort of conversion), bankruptcy law,[410] succession law,[411] and the criminal offence of theft.[412] For example, imagine a third party gains access to a crypto-currency user's private key and sends tokens to another account. Might that constitute theft? Alternatively, in future bankruptcy cases, a debtor may hold an amount of crypto-currency of significant value. Could a court order the tokens be sold to repay creditors?

[178] While the questions may seem simple, the legal classification of blockchain tokens is complicated. Further, whether tokens qualify as property may depend on the legal context and the remedy sought, since an item might qualify as property in some contexts but not in others.[413] For example, the Theft Act 1968 has a specific definition of *property*.[414] Nonetheless, the section below provides an overview of the general arguments that could be raised to determine the property status of tokens in a specific case.

[410] *See* Insolvency Act, 1986, c. 45, pt. 9, § 283(1) (Eng. & Wales); Insolvency Act, 1986, c. 45, pt. 18, § 436(1) (Gr. Brit.); David E. Kronenberg & Daniel Gwen, *Bitcoins in Bankruptcy: Trouble Ahead for Investors and Bankruptcy Professionals?*, 10 PRATT'S J. BANKR. L. 112, 116 (2014) (discussing Bitcoin as property in the US bankruptcy context).

[411] *See* Administration of Estates Act, 1925, c. 23, pt. 3, § 32 (Eng. & Wales).

[412] *See* Theft Act, 1968, c. 60, §§ 1(1), 4(1) (Eng. & Wales); *see also* Law of Property Act, 1925, c. 20, pt. 12, § 205(1)(xx) (Eng. & Wales).

[413] *See generally* Kelvin F.K. Low & Ernie G.S. Teo, *Bitcoins and Other Cryptocurrencies As Property?*, 9 LAW, INNOVATION & TECH. 235, 235 (2017) (discussing whether cryptocurrencies should be considered property and what rights the law should afford them).

[414] *See* Theft Act, 1968, c. 60, § 4(1) (Eng. & Wales) (stating that property "includes money and all other property, real or personal including things in action and other intangible property).

6.4.1 Tokens as Property

[179] At the outset, transferable property rights can be distinguished from non-transferable personal rights.[415] As Baroness Hale noted in OBG v Allan: "*[t]he essential feature of property is that it has an existence independent of a particular person*."[416] "[I]t can be bought and sold, given and received," bequeathed and inherited, and pledged or seized to secure debts.[417]

[180] In National Provincial Bank v. Ainsworth, the House of Lords had to determine whether a deserted wife had any property right in her husband's home.[418] The husband had secured a debt from a bank by a charge on the home.[419] Following non-payment of the debt, the bank sought possession of the home.[420] Lord Wilberforce concluded that the wife's right of occupation of her husband's property was a personal right, enforceable only against her husband.[421] He proceeded to set out a four-step test to be met "[b]efore a right or an interest can be admitted into the category of property," namely: it must be (i) definable; (ii) identifiable by

[415] *See* JAMES PENNER, *The Objects of Property: The Separability Thesis*, *in* THE IDEA OF PROPERTY IN LAW 113 (2000) (arguing that the object of a property right must be separable and distinct from any person, giving rise to alienability); Joanna Perkins & Jennifer Enwezor, *The Legal Aspect of Virtual Currencies*, 31 BUTTERWORTHS J. INT'L BANKING & FIN. L. 569, 569–70 (2016).

[416] OBG v. Allan [2007] UKHL 21, [406] (emphasis added).

[417] *Id.*

[418] *See* Nat'l Provincial Bank v. Ainsworth [1965] AC 1175.

[419] *See id.* at 2.

[420] *See id.*

[421] *See id.* at 19–20.

third parties; (iii) capable in its nature of assumption by third parties; and (iv) have some degree of permanence or stability.[422]

[181] In Armstrong v. Winnington Networks, Stephen Morris QC sitting as deputy High Court judge applied this four-step test to an EU allowance (EUA) to emit carbon dioxide.[423] In this case, the defendant, a German company, had purchased EUAs from a third party, who had fraudulently obtained them from the claimant.[424] The claimant, a UK trader in EUAs, brought a claim of proprietary restitution against the defendant.[425] Stephen Morris QC concluded that the EUA met the four-step test, since it (i) could be defined as the sum total of rights and entitlements conferred on the holder under the Emissions Trading Scheme legislation (ETS); (ii) was identifiable through its unique reference number; (iii) was transferable under ETS; and (iv) had permanence and stability through entries on the registry. Consequently, it was property at common law.[426]

[182] It seems likely that many tokens on blockchain-based applications will also satisfy this test.[427] They can be defined as the right to control the token; are identifiable through entries on the blockchain; can be transferred by submitting transactions; and are registered with a high degree of permanence and stability.[428] This suggests that holders of digital tokens could have a property interest under common law.

---

[422] *See id.* at 20.

[423] *See* Armstrong DLW GmbH v. Winnington Networks [2012] EWCH (Ch) 10, [7].

[424] *See id.* at 425.

[425] *See id.*

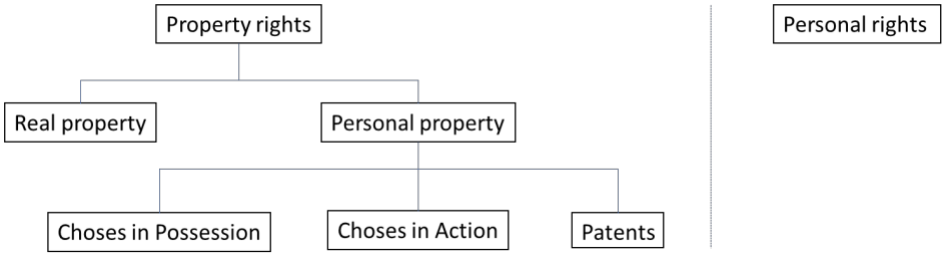
[426] *See id.* at 426.

[427] *See* George Walker, *Financial Technology Law—A New Beginning and a New Future*, 50 INT'L LAW 137, 205 (2017).

[428] *See id.* at 206.

[183] However, classifying that property interest is more difficult.[429] Common law distinguishes between real property (land) and personal property (all other property).[430] Personal property is traditionally further split into choses in possession and choses in action.[431] Patents are granted a separate property status by law as a form of personal property without being a chose in action.[432]

Figure 4. Overview of Property Rights in England and Wales



6.4.2 Tokens as Choses in Possession

[184] Choses in possession are tangible things of which a person may have physical possession and which are capable of transfer by delivery.[433] Since digital tokens do not exist in physical form, they would not qualify

[429] *See id.* at 205.

[430] *See* ROGER J. SMITH, PROPERTY LAW 8 (8th ed. 2014); *see also* MICHAEL BRIDGE, PERSONAL PROPERTY LAW 10 (4th ed. 2015).

[431] *See* BRIDGE, *supra* note 430, at 12; SMITH, *supra* note 430, at 8.

[432] *See* Patents Act 1977 c. 37, pt. 1, § 30(1) (UK). *See generally* BRIDGE, *supra* note 430, at 14 (stating that patents are in a select group in which their intangible property rights are greater than their tangible ones).

[433] *See* BRIDGE, *supra* note 430, at 12.

as choses in possession.[434] However, Green and Randall have argued that the law should recognise that the essential elements of possession can be exercised over digital assets that bear the characteristics of excludability and exhaustibility.[435] Tokens are susceptible to exclusive access, control, transfer, and loss through the associated private key, in a manner functionally similar to things in physical possession.[436] This could argue in favour of recognising a digital token as a chose in *virtual possession* or as a further form of *intangible property* that is capable of possession.[437]

[185] However, case law militates against recognizing possession of digital assets. In Your Response v. Business Media, the Court of Appeals sought to determine whether an electronic database was a form of property capable of possession, such that it could be subject to a possessory lien.[438] Lord Justice Moore-Bick held that while Green and Randall made a powerful case, the course they proposed departed significantly from existing case law.[439] He did not consider this course open to the court, which may have to await the intervention of Parliament.[440] In Armstrong v. Winnington Networks, Stephen Morris QC reached a similar

[434] *See generally* Personal Property, (2013), § 3, 80 HALS. STAT. (5th ed.) 801, 834 (distinguishing physical and legal possession).

[435] *See* SARAH GREEN & JOHN RANDALL, THE TORT OF CONVERSION 120 (2009).

[436] *See* Perkins & Enwezor, *supra* note 415, at 569–70.

[437] *See id.* at 570.

[438] *See* Your Response v. Datateam Business Media [2014] EWCS (Civ) 281 (Eng.).

[439] *See id.* at [27].

[440] *See id.*

conclusion.[441] While recognising that an EUA could be considered similar to a chose in possession, Stephen Morris QC held that the current state of the law did not allow for a conclusion that a thing, which existed only in electronic form could be the subject of actual possession.[442]

[186] Given the above, it is unlikely that a court in England and Wales would recognise a digital token as a chose in possession. Instead, it seems likely that legislation would be required to introduce a new category of *choses in virtual possession*.[443] Doing so would arguably provide a degree of functional equivalence between digital and physical assets.[444] However, as Lord Justices Davis and Floyd warned in Your Response v. Business Media, extending possession to intangible items could have significant unintended consequences,[445] particularly given the many contexts in which a definition of property applies and the various types of digital assets which could be subject to virtual possession. A full discussion of this issue is beyond the scope of this paper. The issue would likely benefit from further research.

[441] *Compare* Your Response V. Datateam Business Media [2014] EWCS (Civ) 281, [27] ("to take the course which they propose would involve a significant departure from the existing law), *with* Armstrong DLW GmbH v. Winnington Networks [2012] EWHC (Ch) 10, [51] (Eng.) (stating that "the current state of the law has not developed to the point where something which exists in electronic form only is to be equated with a physical thing of which actual possession is possible.").

[442] *See* Armstrong DLW GmbH v. Winnington Networks [2012] EWHC (Ch) 10, [51] (Eng.).

[443] *See* Walker, *supra* note 427, at 206.

[444] *See* GREEN & RANDALL, *supra* note 435, at 131.

[445] *See* Your Response v. Datateam Business Media [2014] EWCS (Civ) 281, [41] (Eng.).

6.4.3 Tokens as Choses in Action or "Other Intangible Property"

[187] Choses in action covers all personal rights of property relating to intangible items which can only be claimed or enforced by legal action (and not by taking physical possession).[446] This category covers various kinds of property including debts, rights under contract, and shares, as well as various forms of intellectual property, e.g. copyright, design rights, and trademarks.[447] For example, the money a customer stores with a bank is a chose in action.[448] The customer deposits money and the bank owes the customer a debt. The debt is a right of action that can be transferred to other persons.[449]

[188] Whether a digital token will constitute a chose in action is likely to depend on the circumstances of the particular case and in particular whether the token represents a specific right against the issuer. In some cases, a token may represent a right that is substantially similar to an existing chose in action, such as a debt or share in the issuing company. In such cases, the token is likely to qualify as a chose in action. It arguably functions like a digital version of a *documentary intangible*, like a cheque or a bill of lading; where a physical document represents an intangible chose in action.[450] Such tokens further resemble a *transferable document or instrument* contained in a reliable electronic record under the UNCITRAL Model Law on Electronic Transferable Records, which sets

[446] Choses in Action, (2017) § 1, 13 HALS. STAT. (5th ed.) 1, 1.

[447] *See id.* at 5–9.

[448] *See* SMITH, *supra* note 430, at 4–5; *see also* BRIDGE, *supra* note 430, at 21.

[449] See *id.*

[450] *Cf.* Perkins & Enwezor, *supra* note 415, at 570.

out model rules for the legal recognition of electronic transferable records "on a technologically neutral basis."[451]

[189] In other cases, as set out above in Section 6.3, digital tokens may be sold as part of an ICO by a particular business and give the user a contractual right against the issuer.[452] For example, the token may give the holder a right to use a particular service (a so-called *utility token*) or to share in the company's profits (an *investment token*). In such cases, the tokens are likely to constitute a chose in action, if the counterparty and rights associated with the token are clearly defined. They resemble other forms of non-personal, transferable contractual obligations. The key issue in this respect is not whether the blockchain is centralised or distributed at the level of nodes or miners, but whether the token represents a clear obligation held by users against the developers/issuers. For example, a company could issue special ICO tokens on top of the distributed Ethereum blockchain.

[190] However, not all ICO tokens give purchasers a clear right against the issuer. For example, the terms of the EOS ICO Token Purchase Agreement state explicitly that the tokens have no rights, uses, or attributes.[453] Other tokens only give purchasers an undefined right to use a platform that may be launched at some future time.[454] In such cases, the argument for classifying the token as a chose in action is significantly weaker.

[191] The classification of cryptocurrency tokens is even more difficult. First, unlike several other types of choses in action (e.g. debts), there is no

---

[451] *See UNCITRAL Model Law on Electronic Transferable Records*, UNITED NATIONS COMM'N INT'L TRADE L. 5, 37–38 (2018).

[452] *See* discussion *supra*, Section 6.3.

[453] *EOS Token Purchase Agreement*, BLOCK.ONE (Sept. 4, 2017), https://eos.io/documents/block.one%20%20EOS%20Token%20Purchase%20Agreement%20-%20September%204,%202017.pdf [https://perma.cc/HX49-AX4B].

[454] *See, e.g.*, *SNT Creation*, *supra* note 376, at 1, 2.

specific counterparty with an obligation.[455] As set out in Section 2, a Bitcoin does not give rise to any rights against others; it only gives a user the exclusive technical control over an amount of Bitcoin, i.e. entries in the UTXO database.[456] Further, as set out in Section 3.1 and 3.3, there is no specific issuing party; only a group of core developers who manage the Bitcoin software.[457]

[192] Second, the existing types of choses in action without a specific obligor (like copyright) arise from legislation.[458] As noted above, in Armstrong v. Winnington Networks, Stephen Morris QC determined that an EUA constituted property at common law.[459] In particular, it was a form of *intangible property*, being either a chose in action or some form of *other intangible property*.[460] In reaching this conclusion, he applied a three-step test: (i) there must be a statutory framework conferring an entitlement; (ii) the entitlement must be transferable; and (iii) the entitlement must have value.[461] In all existing cases, tokens on distributed blockchain applications lack a legislative framework and will fail the first prong of this test.[462]

---

[455] *See* Low & Teo, *supra* note 413, at 246.

[456] *See generally* Andresen, *supra* note 82 (stating that the UTXO database serves to prohibit double-spending or spending bitcoins that do not exist).

[457] *See* Christopher, *supra* note 164, at 150.

[458] *See* Noel McGrath, *Transacting in a Vacuum of Property Law* (Transnat'l L. Inst. Think!, Paper No. 22/2016), https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2786206 [https://perma.cc/7E9K-AFLN].

[459] *See* Armstrong DLW Gmbh v. Winnington Networks [2012] EWHC 10, [50] (Eng.).

[460] *See id.* at 442.

[461] *See id.* at 440–41.

[462] *See* McGrath, *supra* note 458.

[193] As a result, it is difficult to recognise distributed blockchain tokens as choses in possession or choses in action. On a traditional view, if they are neither choses in possession nor in action, then they are arguably not property at all.[463] The question then arises whether tokens could constitute a form of *other intangible property*. However, it is unclear whether the common law as applied in England and Wales recognises a category of *other intangible property* (other than choses in action and patents). On the one hand, in Armstrong v. Winnington Networks, Stephen Morris QC appeared open to recognising other forms of intangible property.[464] Further, the definition of property in the Theft Act 1968 explicitly includes both "things in action" and "other intangible property."[465] On the other hand, in Your Response v. Business Media, Lord Justice Moore-Bick considered it "very difficult to accept that the common law recognise[d] the existence of *intangible property* other than choses in action," and patents.[466]

[194] Given the above, the property status of digital tokens on distributed blockchain applications under property law is uncertain.[467] The classification as either a chose in action or a chose in possession can have significant practical consequences. For example, the tort of conversion is

[463] *Cf.* Ken Moon, *The Nature of Computer Programs: Tangible? Goods? Personal Property? Intellectual Property?*, 31.EUR. INTELL. PROP. REV. 1, 15 (2009) (stating that personal property is either a chose in action or a chose in possession).

[464] *See generally* Armstrong DLW Gmbh v. Winnington Networks [2012] EWHC 10 (Ch), [52]–[60] (Eng.) (analyzing EUA as intangible property by discussing case law).

[465] *See* Theft Act, 1968, c. 60, § 4(1) (Eng. & Wales).

[466] Your Response v. Datateam Business Media [2014] EWCS (Civ) 281, [25]–[26] (Eng. & Wales) (emphasis added) (citing Lord Justice Fry's holding in Colonial Bank v. Whinney (1885) 30 Ch. D. 261 that "all personal things are either in possession or in action [and] the law knows no tertium quid between the two," as upheld in the House of Lords (1886) 11 App. Cas. 426).

[467] *See* discussion *supra*, at [193].

only available for choses in possession, not choses in action.[468] The issue has already arisen before a US court, where a claimant is seeking damages for, or the return of, over 1m BTC under the tort of conversion from a defendant who allegedly wrongfully deprived the claimant of the tokens.[469] Until the status of such tokens is clarified by case law or legislation, this issue may cause consternation for lawyers and courts in future divorce, bankruptcy, criminal law, and succession cases.

6.5 Blockchain Databases and Intellectual Property Law

[195] Various forms of intellectual property may apply to different aspects of blockchain technology. First, blockchain-related inventions that provide a novel, non-obvious technical solution that is capable of industrial application may be patentable.[470] The core components of blockchain technology are public knowledge and many developers may opt to share their code freely, using an open-source license.[471] For example, Bitcoin and Ethereum's software are available under various open-source license terms.[472] Nonetheless, companies are filing patent

---

[468] *See* OBG, v. Allan, [2007] UKHL 21, [384] (UK).

[469] *See* Alex Hern, *Self-Proclaimed Bitcoin 'Creator' Sued for $10bn*, GUARDIAN, (Feb. 27, 2019, 6:11 PM), https://www.theguardian.com/tehcnology/2018/feb/27/bitcoin-craig-wright-self-proclaimed-creator-sued-10bn-former-coding-partner-family [https://perma.cc/4WSK-NK48].

[470] *See* Tim Press, *Patent Protection for Computer-related Interventions*, *in* COMPUTER LAW (Chris Reed ed., 7th ed. 2012).

[471] *Cf.* Peter Van Valkenburgh, *What is "Open Source" and Why Is It Important for Cryptocurrency and Open Blockchain Projects?*, COIN CTR. (Oct. 17, 2017), https://coincenter.org/entry/what-is-open-source-and-why-is-it-important-for-cryptocurrency-and-open-blockchain-projects [https://perma.cc/ZA5N-TSMT] (stating that open source software and decentralization is important in blockchain technology).

[472] *See, e.g.*, *Licensing*, GITHUB, https://github.com/ethereum/wiki/wiki/Licensing [https://perma.cc/UL33-296N]; *MIT License*, GITHUB, https://github.com/bitcoin/bitcoin/blob/master/COPYING [https://perma.cc/9QWT-Y52Y].

applications for improvements to existing blockchain technology, including relating to security and encryption techniques.[473] For example, Accenture has reportedly been awarded a patent for its editable blockchain technology.[474] A patent will grant the right holder exclusive rights to the commercial exploitation of the protected invention.[475]

[196] Second, the information stored on a specific blockchain database could be protected by copyright. Under the EU's 1996 Directive on the legal protection of databases (the Databases Directive), EU member states are required to provide copyright protection for databases, which "by reason of the selection or arrangement" of contents "constitute the author's own intellectual creation."[476] To attract copyright protection, the author must have expressed his creative ability in an original manner by making free and creative choices in setting up the database.[477] By contrast, the database will lack the required originality, if the setting up was dictated by technical considerations.[478] Since the information stored on a blockchain will ordinarily be determined by technical design decisions based on a platform's desired functionality, it seems likely that most blockchain databases will not be protected by copyright under EU law.

---

[473] *See A Rush to Patent the Blockchain is a Sign of the Technology's Promise*, ECONOMIST (Jan. 12, 2017), https://www.economist.com/news/business/21714395-financial-firms-and-assorted-startups-are-rushing-patenttechnology-underlies [https://perma.cc/7U9R-FSCH].

[474] Stan Higgins, *Accenture Awarded Patent for 'Editable Blockchain' Tech*, COINDESK (Sept. 28, 2017, 9:00 AM), https://www.coindesk.com/accenture-awarded-patent-editable-blockchain-tech/ [https://perma.cc/3DFX-MZKZ].

[475] *See Rights Granted Under U.S. Patent Law*, BITLAW, https://www.bitlaw.com/patent/rights.html [https://perma.cc/D2FW-F4P4].

[476] Directive 96/9, of the European Parliament and of the Council of March 1996 on the Legal Protection of Databases, 1996 O.J. (l77) art. 3(1).

[477] *See id.*

[478] *See* Case C–604/10, Football Dataco v. Yahoo! UK, 2012 EUR–Lex CELEX LEXIS 115 (Mar. 1, 2012).

[197] Third and finally, a blockchain database could be protected as a database under the Databases Directive's *sui generis* protection right for databases.[479] This *sui generis* right protects databases for which there has been (qualitatively or quantitatively) a substantial investment in the obtaining, verification, or presentation of their contents.[480] This right is not affected by making the database publicly accessible.[481]

[198] The Database Directive defines a database as "a collection of independent works, data or other materials which are arranged in a systematic or methodical way and individually accessible by electronic or other means."[482] As set out in Section 2.1 above, a blockchain uses blocks linked through hash pointers to store transactions records, which can be individually accessed through lookup.[483] Given this, many blockchain applications will likely qualify as databases. To qualify for a *sui generis* protection right, there must have been a substantial investment in the creation of the database.[484] According to the European Court of Justice, an investment in the presentation of the contents of a database concerns "the resources used for the purpose of giving the database its function of processing information, that is to say those used for the systematic or methodical arrangement of the materials contained in that database and the

[479] *See generally* Directive 96/9, *supra* note 476 (stating the object of protection, the rights and obligations of lawful users, exceptions to the *sui generis* right, term of protection, and beneficiaries of protection under the *sui generis* right).

[480] *See id.* at 7.

[481] *See* Case C–203/02, British Horseracing Board v. William Hill, 2004 EUR–Lex CELEX LEXIS 333 (June 8, 2004).

[482] Directive 96/9, *supra* note 476, at art.1.

[483] *See* discussion *supra* Section 2.1.

[484] *See* Case C–338/02, Fixtures Marketing v. Svenska Spel AB, 2004 EUR–Lex CELEX LEXIS 696 (Nov. 9, 2004) (holding that "the expression 'investment in . . . the obtaining, verification or presentation of the contents' of a database must be understood, generally, to refer to investment in the creation of that database as such.").

organisation of their individual accessibility."[485] It could be argued that the operator(s) of a new, centralised blockchain platform make a substantial investment in setting up the blockchain database. For instance, they might invest in the presentation of the database by deploying human, financial, and technical resources in writing the blockchain software and then dedicating hardware to running nodes and miners.[486]

[199] Nonetheless, it is unclear whether such investments qualify as a substantial investment in the creation of a database. In practice, this may depend on each specific platform's design and functionality and whether extending protection aligns with the purpose of the *sui generis* right, namely to "promote the establishment of storage and processing systems for existing information."[487]

[200] Given the above, certain blockchain databases may be protected under the *sui generis* right. If so, and provided they have sufficient links to an EU Member State,[488] the right holders of a centralised platform would have the right to prevent extraction and re-utilization of (all or a substantial parts of) the contents of that database.[489] This may be relevant to instances of *forking*, where a third-party takes an existing blockchain database as the basis for starting a new blockchain platform (see Section 3.3 above).[490]

---

[485] *Id.*

[486] *See id.*

[487] *Id.*

[488] *See* Directive 96/9, *supra* note 476, at art. 11 (requiring beneficiaries to be nationals of an EU Member State, or have their habitual residence in the territory of the Community, or to be companies and firms formed in accordance with a Member State's laws with their registered office, central administration, or principal place business within the Community).

[489] *See id.* at 5, 7.

[490] *See* discussion *supra* Section 3.3 (discussing forking and starting new blockchain platforms from existing blockchains).

[201] Determining whether there has been a *substantial investment*—and if so who holds the rights - would be more difficult for distributed platforms. The database right is owned by the *maker* of the database, being *the person who takes the initiative and the risk of investing*.[491] However, as set out in Sections 3.1 and 3.3 above, various groups may contribute to the creation of an open, distributed blockchain, with developers writing the initial software, and nodes and miners investing in hardware that stores and updates the database. It is unclear whether these activities, taken separately, amount to *substantial investments*, and if so, which of the activities would suffice for a party to qualify as one of the database *makers*.

6.6 Digital Autonomous Organisations and Company Law

[202] Smart contracts can be used to manage the assets and determine the structure, purposes, and functioning of an organisation, known as a Decentralised Autonomous Organization (DAOs).[492] For instance, a DAO could have a number of members who could together, say by two-thirds majority, decide how to spend funds. This replicates some of the elements of a legal company, such as dividend-receiving shareholders and tradable shares, but using only smart contracts for enforcement.[493] As a result, a DAO could allow strangers to contribute capital towards a common enterprise pseudonymously, without needing to trust a management team to exercise control over the company and its associated capital.

[203] However, most jurisdictions feature formal requirements for creating a company, such as registration with a central registry like the UK's Companies House.[494] As a result, a DAO might not qualify as a

[491] *See* Directive 96/9*, supra* note 476, at Recital 41.

[492] *See* Buterin, ETHEREUM WHITE PAPER, *supra* note 109, at 1.

[493] *See id.* at 23.

[494] *See Set Up a Private Limited Company*, GOV.UK, https://www.gov.uk/limited-company-formation [https://perma.cc/9ZJN-G7B7].

recognised *legal person* or offer shareholders limited liability. Participants in a DAO may face significant legal risk, potentially being held personally responsible for the DAO's liabilities.[495]

[204] Further, DAOs suffer from the same risk of human error as smart contracts, as illustrated by the hack of *The DAO* set up on the Ethereum platform. *The DAO* was set up in 2016 as a funding vehicle for Ethereum-based projects, such as using *smart locks* to let people share their physical assets (e.g. cars, boats, apartments).[496] It attracted over U.S. $160 million in Ether funding from around 11,000 members.[497] However, a hacker exploited a vulnerability in *The DAO*'s smart contracts and siphoned off almost a third of its funds.[498]

[205] Since Ethereum is an open, distributed platform, the only way to *correct* the effects of this hack (without the hacker's cooperation) was to convince nodes to replace their local copy of the blockchain with a chain in which the funds were still held by *The DAO*.[499] In the event, this was achieved and a majority of Ethereum nodes moved to the new chain,

---

[495] *See* Dirk A. Zetzsche et al., *The Distributed Liability of Distributed Ledgers: Legal Risks of Blockchain* 36 (Univ. New South Wales L. Res. Series, Paper No. 52, 2017), https://ssrn.com/abstract=3018214 [https://perma.cc/AZ9L-LZMW].

[496] *See* Giulio Prisco, *Slock.it to Introduce Smart Locks Linked to Smart Ethereum Contracts, Decentralize the Sharing Economy*, BITCOIN MAG. (Nov. 5, 2015, 1:05 PM), https://bitcoinmagazine.com/articles/slock-it-to-introduce-smart-locks-linked-to-smart-ethereum-contracts-decentralize-the-sharing-economy-1446746719/ [https://perma.cc/R6JK-9LLJ]; c*f.* Falkon, *supra* note 501 ("members of the Ethereum community announced the inception of The DAO, which was also known as Genesis DAO. It was built as a smart contract on the Ethereum blockchain.").

[497] *See* Voshmgir Shermin, Disrupting Governance with Blockchains and Smart Contracts, *in* 26 THE FUTURE OF MONEY AND FURTHER APPLICATIONS OF THE BLOCKCHAIN 499, 506. (2017).

[498] *See id.*

[499] *See* discussion *supra* Section 3.3.2.

thereby reversing the attack.[500] A minority of users refused to do so and stayed on the original branch, which was renamed "Ethereum Classic."[501] However this was a particularly high-profile, one-off incident, affecting a large number of participants. Such contentious hard forks may be unlikely for issues affecting fewer parties or deemed by the community as insignificant compared with the cost of implementing a fork.

[206] As noted above, centralised platforms support reversibility better.[502] A single TTP or group of trusted nodes can revert transactions and modify balances if necessary, for instance to enforce court decisions.[503]

IV. CONCLUSIONS

7.1 Blockchain Technology

[207] Blockchain technology utilises two core technologies to create a persistent, tamper-evident record of transactions between parties whose identity has been authenticated.[504] First, hash pointers link blocks of transactions together, such that tampering with transaction data in past blocks breaks the links between the blocks.[505] Second, Public Key Infrastructure establishes parties' identities, with private keys used to encrypt data and provide digital signatures.[506]

---

[500] *See* NISTIR OVERVIEW, *supra* note 6, at 33.

[501] *See id.* at 41–42.

[502] *See* discussion *supra* Section 3.3.2., at [71].

[503] *See* Buterin, *Public and Private Blockchain*, *supra* note 138.

[504] *See generally* discussion *supra* Section 2 (discussing data integrity and identity authentication).

[505] *See* discussion *supra* Section 2.1.2, at [16]–[17].

[506] *See* discussion *supra* Section 2.2, at [21]–[23].

[208] Blockchain technology can be deployed in various ways to create platforms with different features, including with regard to:

(i) Access: who can propose new transactions to be added to the ledger;
(ii) Control:
  a. storage: who stores a copy of the ledger;
  b. mining and consensus: how to create new blocks and determine when blocks should be added to the existing ledger;
  c. governance: who controls the platform's underlying software;
(iii) Visibility: who can view the ledger;
(iv) Identity: whether users are identifiable; and,
(v) Automation: whether the platform supports smart contracts.

[209] Early cryptocurrencies were set up with the following features: an open, distributed platform (where anybody can store a copy of the ledger as a node, and contribute to the process of adding new blocks as a miner); open/permissionless access (where anybody can join as a user); and, a public database (where anybody can view the transaction records stored on the blockchain or store a copy of the ledger).[507] In order to ensure the consistency of the many distributed copies and to ward off attackers, these systems rely on resource-intensive consensus protocols.[508] They offer strong data integrity, since it is much harder to tamper with large numbers of distributed copies, as well as high resilience.[509] However, the need to support thousands of small nodes, and run proof of work, limits transaction throughput and increases costs.

[507] *See* discussion *supra* Section 3, at [32].

[508] *See* discussion *supra* Section 3.1.4.

[509] *See* discussion *supra* Section 3.1.4.

[210] These systems also provide a high level of transparency, since anyone can view all transaction data.[510] To afford users some level of privacy, the systems are pseudonymous: users are identified only by their public key and an address, which does not directly reveal a real-world identity.[511]

[211] By contrast, future applications of blockchain will include more centralised platforms, with closed/permissioned use, and a private database. In such arrangements, a TTP or group of trusted nodes store copies of the ledger, add new blocks, and determine which users can access the platform and view the ledger.[512] This requires users to have a level of trust in the centralised blockchain administrator(s) to maintain an accurate ledger and keep the ledger secure and the system running.[513] Since there are only a limited number of trusted nodes, such systems do not need resource-intensive consensus protocols. Further, by working with a small number of high-capacity nodes, the systems may be better able to scale and process large numbers of transactions.

[212] In sum, from a technical perspective, whether to use an open, distributed or more centralised approach will depend on the degree of trust needed and the application's requirements for data integrity, resilience, scalability, and confidentiality.[514] It is not clear that using a centralised blockchain offers significant advantages over existing database solutions,

[510] *See* Buterin, *Public and Private Blockchain*, *supra* note 138.

[511] *See* discussion *supra* Section 4.2.

[512] *See* discussion *supra* Section 3, at [51]–[54].

[513] *See* discussion *supra* Section 3, at [28].

[514] *Cf.* Gideon Greenspan, *Blockchains vs Centralized Databases*, MULTICHAIN (Mar. 17, 2016), https://www.multichain.com/blog/2016/03/blockchains-vs-centralized-databases/ [https://perma.cc/HA5A-5798] (comparing various aspects of blockchains and centralized databases to show that choosing between the two "comes down to a series of trade-offs").

particularly when traditional databases can perform many of the same functions.[515]

7.2 Blockchain and the Law

[213] Given the diversity of possible blockchain platform designs, no *one-size-fits all* legal analysis is possible. Instead, each application of blockchain technology will need to be considered on its facts. From a legal perspective, closed, centralised platforms are generally likely to entail lower risks in the areas we have reviewed. The TTP or group of trusted nodes may be able to coordinate compliance, limit visibility of records, and reverse past transactions if necessary. Achieving these goals is harder on open, distributed platforms that deliberately lack a central administrator with control over the ledger.

[214] To illustrate this point, we reviewed issues that may arise in various areas of the law. For example, users on blockchain platforms engage in activities, such as setting up smart contracts and issuing ICOs, that have characteristics closely resembling established legal concepts, such as contracts and securities. Engaging in these activities may have significant legal consequences. In many cases, the legal implications are affected by the blockchain platform's design, as set out below.

7.2.1 Contract Law

[215] The legal concept of *contract* is generally not subject to formal requirements. As a result, communications relating to smart contracts may qualify as enforceable legal contracts, giving rise to legal obligations that go beyond the underlying computer code. Smart contracts may entail particularly high risks, since they combine automatically executed code

[515] *See* e.g. Arvind Narayanan, *'Private Blockchain' Is Just a Confusing Name for a Shared Database*, FREEDOM TO TINKER (Feb. 18, 2014),https://freedom-to-tinker.com/2015/09/18/private-blockchain-is-just-a-confusing-name-for-a-shared-database/e [https://perma.cc/A5MV-ZSSK].

written by fallible humans with a blockchain's persistent, tamper-evident data structure. For example, a bug in the smart contract's code may lead to non-performance, or incorrect performance of a legal contract. The ease of correcting such mistakes will depend on the type of blockchain platform involved. Centralised blockchain platforms can support reversibility better: the TTP or group of trusted nodes may be able to correct any mistakes by amending erroneous transactions in the ledger, since they control the copies. However, on an open, distributed platform, correcting past mistakes would be more difficult, potentially requiring cooperation from thousands of nodes.

7.2.2 Data Protection Law

[216] If a blockchain platform is used to process personal data, the users, nodes, and miners of blockchain platforms may be either data controllers, processors, or potentially both. If so, they will need to comply with data protection obligations and may be exposed to substantial penalties for breaches of data protection laws. With open, distributed platforms, even if all parties involved were deemed joint controllers, it is not clear how they would comply with their obligations (such as to establish responsibilities by contract and respond appropriately to the exercise of data subjects' rights).

7.2.3 Securities and Property Law

[217] Depending on their function, the tokens sold in some ICOs may be deemed to be securities, in which case their promoters will need to comply with securities laws, including obligations to provide investors with appropriate information. Whether the tokens issued under ICOs qualify as the legal *property* of their users is currently uncertain and will likely depend, to some extent, on the rights the token purchaser holds against the issuer. In England and Wales, a transferable token that gives the user a definable right against a specific issuer may qualify as a chose in action. Conversely, the property status of cryptocurrency tokens on open, distributed applications like Bitcoin is unclear.

7.2.4 Intellectual Property Law

[218] Some blockchain databases may qualify for a *sui generis* database protection right. If so, the right holder would have the right to prevent extraction and re-utilization of the contents of that database. Determining the *maker* of the database (who is awarded the right) could be fairly straightforward for centralised platforms, but may be more challenging with open, distributed platforms.

7.2.5 Company Law

[219] Finally, establishing a company is generally subject to formal requirements, such as registration with a central agency. As a result, DAOs are unlikely to qualify as legal persons and, as a result, participants will not necessarily benefit from limited liability. As with smart contracts, DAOs combine human fallible code with a blockchain's persistent database. Should a bug in the code lead to liability for damages, each DAO participant could conceivably be liable. As noted above, any such damages would be much more difficult to reverse in the case of open, distributed platforms.

[220] Ultimately, the legal uncertainties and risks associated with the use of open, distributed platforms may limit their adoption. In some cases, technical solutions may be available, or be developed, to provide greater certainty and reduce such risks. In other cases, legislators, regulators, and legal advisers may need to design novel legal solutions.