BLOCKCHAIN USE CASES IN HEALTHCARE

a thematic report prepared by

THE EUROPEAN UNION BLOCKCHAIN OBSERVATORY & FORUM

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About this report

The European Union Blockchain Observatory & Forum has set as one of its objectives the analysis of and reporting on a wide range of important blockchain themes, driven by the priorities of the European Commission and based on input from its Working Groups and other stakeholders. As part of this it will publish a series of thematic reports on selected blockchain-related topics. The objective of these thematic reports is to provide a concise, easily readable overview and exploration of each theme suitable for the general public. The input of a number of different stakeholders and sources is considered for each report. For this paper, these include:

- Members of the Observatory & Forum's Working Groups as well as the Obeservatory's Convergence Sub-Working Group (please see next page).
- Input from participants at the "Use cases in healthcare" workshop held in Frankfurt on 4 September, 2019.
- Input from the Secretariat of the EU Blockchain Observatory & Forum (which includes members of the DG CONNECT of the European Commission and members of ConsenSys).

CREDITS

This report has been produced by ConsenSys AG on behalf of the European Union Blockchain Observatory & Forum.

Written by: Tom Lyons, Ludovic Courcelas
Thematic Report Series Editor: Tom Lyons
Report design: Benjamin Calméjane

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DISCLAIMER

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Executive summary

There is no doubt that the healthcare industry faces a number of serious challenges. In this paper we examine how blockchain might be used to help address them.

We begin with looking at the problems from the perspective of the individual and his or her health data. Despite how vital and valuable personal health information (PHI) is, most individuals have no control over it. With the help of blockchain, we could apply self-sovereign identity paradigms to health data, allowing individuals to store their own health records and control access. This could have a number of advantages. It would make it easier for individuals to aggregate all their health-related information themselves, and so have an overview of such data. Once aggregated, individuals could choose to take their data "to market" via blockchain-based patient-mediated health data exchanges. Such markets would make it possible for individuals to share, rent or sell some of their personal health data to interested parties, allowing them to both support research but also, if they wish, monetise their health data. Using new federated learning and secure computational techniques, this could in theory be done in a privacy-preserving way, so that the data itself is never revealed nor leaves the possession of its owner.

Such markets could be a boon not just to individuals but also to society as a whole, by making more and better quality data available to the healthcare system. It could have a great impact in promoting healthier lives and improving healthcare outcomes too, by making it easier for individuals to collaborate much more actively with their physicians and other healthcare professionals in their own personal healthcare. This could include facilitating value-based care models, in which physicians are compensated based on outcomes not treatments, as well as provide new means for incentivising healthy behaviour.

We next look at the issues from the perspective of the healthcare industry. As we point out, there is hardly any part of the healthcare system today that isn't data-driven. And while the good news is that there is plenty of health-related data to be had, the bad news is that it is often locked in impenetrable silos and can be hard to find or make use of.

Blockchain could help address many of these issues. It could be combined with the Internet of Medical Things (IoMT) to help ensure the authenticity of IoMT-generated data along the data lifecycle, as well as

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more securely control devices remotely. It could be used to support large-scale health data markets for medical research and development. These could become an important source of high-quality, large-scale data sets that, using the novel techniques already mentioned, could be assembled in privacy and IP-protecting ways. Blockchains could also support clinical trials, helping reduce the cost and complexity of recruiting participants, facilitating remote trials, and potentially enabling safe re-use of data in subsequent trials. Blockchain-based medical supply chain platforms could help fight counterfeit medicines and parts for medical devices by providing reliable provenance information as well as monitoring the entire production chain (often in conjunction with IoT sensors).

We also look at how blockchain could support the administration of healthcare. Self-sovereign health records could help first responders get quick access to a patient's medical history in an emergency, and also simplify admissions and streamline and improve care at doctors and hospitals. Large-scale, tokenised ecosystems for healthcare that bring together all players in the system on one platform could enable new models of healthcare distribution. Decentralised health data and tokenised data markets and incentive schemes could help improve preventive and after care procedures.

Healthcare workers could benefit from blockchain too. Blockchain could be used to set up decentralised accreditation regimes on the self-sovereign identity model, helping relieve some of the serious problems around professional credentialing of doctors. Blockchain could be used as a basis for community-driven organisations for healthcare professionals. These could include tokenised, decentralised marketplaces for doctors and healthcare workers to share services among themselves, as well as introduce new types of grassroots professional associations run under decentralised principles (e.g. DAO for doctors).

Considering that this report was prepared during the height of the COVID-19 pandemic, we also look at how the blockchain community has been responding to the crisis. Among other things, blockchain has been proposed as a means to help mitigate the supply chain disruptions that have caused shortages of the personal protective equipment (PPE) and other medical equipment. It could also be used to support privacy-preserving contact tracing techniques to bring both privacy and transparency to efforts to monitor populations and share COVID-related health data. Blockchain-based solutions have been proposed to help mitigate the effects of lockdowns by enabling straightforward distribution of relief funds and insurance payments, supporting research

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and development of novel methods for treatment and prevention, as well as supporting privacy-preserving approaches to social distancing.

Blockchain for Healthcare

BLOCKCHAIN AND THE GLOBAL HEALTHCARE CHALLENGE

Healthcare has long been recognised as a key blockchain use case. Today, as the COVID-19 pandemic rages, it has become one of the most topical. While the corona virus has shone an intense light on problems in healthcare and related industries like supply chain, the problems – from fraud and abuse to inefficiency and waste to spiralling costs – are well known.

As in other technology-dependent sectors, many of healthcare's most trenchant problems are data problems – and many of the most important solutions will be data solutions. Yet in an industry as large and far-reaching as healthcare, the challenges around accumulating, analysing and exploiting data, as well as safely storing and transporting it, can seem insurmountable. As in other sectors, in healthcare we can observe a strong tension between society's need for big data to support research and care delivery, and the individual's right to privacy and data security. It will not be easy to square this circle.

As we try to show in this paper, we think blockchain can help. It will do so in the context of a number of broader transformations we are currently living through. One is the technological revolution that has seen an unprecedented number of disruptive technologies appear on the scene almost simultaneously, from AI and 3D printing to biotech, genomics, Internet of Medical Things (IoMT) and of course blockchain. We are also experiencing a tipping point in attitudes towards the just use of personal health data (along with personal data in general), as people become more aware of how much personal health data is generated about them and of how little overview and control they have of it. This has all been accompanied by strong steps on the part of regulators to protect personal health information (PHI) and the rights of patients to have a say in its use.[1]

DECENTRALISED PARADIGMS FOR HEALTHCARE

Before we get into the details of how blockchain might be employed in healthcare, we provide here an overview of some of the characteristics of blockchain and blockchain-based systems that are important in a

1 For example the GDPR in Europe or HIPAA in the US.

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healthcare context.

- **Decentralisation.** The main benefit of blockchain in healthcare, as elsewhere, is decentralisation – here loosely defined as an organising principle based on bottom-up, shared, community-run approaches as opposed to top-down, command-and-control ones. This is not a value judgement. Centralised approaches are the norm today and have served society extremely well. But they have weaknesses, too. Centralised systems can represent single points of failure and/or corruption. They tend towards the creation of data silos and can be a hindrance to interoperability. They concentrate the value of data in the hands of the data platform, not necessarily the data producer. They can be hugely attractive "honey pots" for hackers and cyber criminals. The list goes on. The appeal of blockchain is as a tool to replace centralised with decentralised alternatives that either address these weaknesses or offer novel, innovative approaches that weren't possible before.
- **Group consensus on information.** Healthcare relies on sharing data among various groups. This includes personal health information (PHI), research data, insurance information, information on payments, health-related statistics, diagnostic data… the list is almost endless. In most use cases, this information has to pass from one person or organisation to another. This creates a strong need among stakeholders in healthcare for a consensus view of data. Instead of relying on a third party to act as the verifier and distributor of information, blockchains can be used to create shared data and transaction platforms where all stakeholders share the work of arriving at consensus, therefore leading to high trust in the information that is agreed upon.
- **Track and trace of objects and information.** To get a consensus view on data, that data has to be trustworthy. In healthcare as in other industries there is a great need to improve information supply chains – that is, to understand where information comes from, what has happened to it along the data lifecycle, and so on. Blockchain works very well for such kinds of use cases.
- **Shared data history/audit.** Whether in pharmaceutical or medical equipment recalls, insurance claims, billing and revenue management, litigation or in many other cases, an "agreed-upon version of the truth" that is reliable over time is extremely valuable. Blockchain provides strong tools for decentralised, trustworthy and auditable shared record-keeping in the form of immutable, distributed ledgers.
- **Digitisation and document sharing.** A mundane but often crucial

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component of many business processes is document sharing. While the healthcare industry is highly digitised already, document management often does not go beyond sharing PDFs. Blockchain can be used to build common, trusted document libraries with access control and audit trails. Blockchain-based documents, including contracts, can also in theory be made interactive and dynamic, linked to outside data sources and containing their own business logic.

- **Tokenisation for data and value transfer.** Blockchains are by their nature peer-to-peer transaction environments. Through the process of tokenisation, any piece of data can be sealed, given a unique ID, and then shared through the network. These can be tokens of value, like cryptocurrencies, or tokens representing discrete pieces of information, for instance a health record. Once on the blockchain, these tokens can be exchanged directly between parties. The advantages of such peer-to-peer (P2P) transactions in money or information include immediate settlements, the opportunity to greatly reduce or eliminate reconciliation costs and streamlining processes, as well as the ability to develop novel, decentralised payment and incentive mechanisms.
- **Shared/automated business processes and workflows.** Smart contracts run on a blockchain can be used to automate business processes and transactions, from simple escrow arrangements to complex workflows. Automation can be a big driver of efficiency gains and cost reduction, and so holds great promise in a number of healthcare industry use cases.
- **Avoiding third-party trust and bottlenecks.** Shared industry utilities, run by a third party for industry stakeholders, are commonplace in many sectors, including healthcare. Yet they are not always an ideal solution. For one, there can be a reluctance on the part of industry participants – for example, pharmaceutical or insurance companies – to appoint a single third party as the single source of truth for fear that that party would gain outsized power from the information derived from transactions. For another, it can be extremely difficult to engineer a large-scale platform, whether a private one or a shared utility, that is able to meet the complex and evolving needs of an industry as large as healthcare. One advantage of decentralised platforms is that, being built on bottom-up principles, they can often evolve in a flexible, organic way over time.

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DECENTRALISED IDENTITY FOR HEALTHCARE

As we wrote in our report on blockchain and digital identity,[2] today's centralised digital identity approaches are broken. The issues – from security, to surveillance, to identity theft, to monetisation of identity data by third parties – are well known. Along with advances in areas like secure hardware (e.g., smartphones) and cryptography, blockchain is seen as a core component in developing viable decentralised identity frameworks. As opposed to the centralised approach, where a third party provides credentials and maintains identity information for an individual, in the decentralised identity world users create their own digital identities and then attach verifiable credentials and other information to that identifier in a way that makes it possible to prove it is genuine. The user can then produce these credentials as needed.

In self-sovereign identity (SSI), an important subset of decentralised identity, the individual has both a means of generating and controlling unique identifiers as well as some facility to store related identity data. This could comprise verifiable credentials as described above, but could also be data from a social media account, a history of transactions on an e-commerce site, or attestations from friends or colleagues – or, as we will see, health records and health-relevant information. Decentralised identity in general, and SSI in particular, are likely to play an important role in decentralising healthcare.

PRIVACY-PRESERVING AND SECURE COMPUTING FOR HEALTHCARE

Another key building block will be secure computing. Here we are not speaking of blockchain, but of a number of groundbreaking advances in cryptography and computer science that make it possible to run applications on data while keeping that data encrypted. These techniques include:

- **Zero-knowledge proofs:** a mathematical way to prove that you know something without revealing what exactly it is you know. This makes it possible to present an irrefutable claim without exposing the data behind it. The classic (if somewhat overused) example is the ability to prove the claim "I am over 18 years old" without revealing your birthday.

2 Blockchain and Digital Identity, EU Blockchain Observatory & Forum, 2 May 2019.

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- **Homomorphic encryption:** the holy grail of secure computation, the idea is to allow computation on encrypted data by finding a function that generates an encrypted result which would be the same as the result of the operations had they been performed on the unencrypted data.
- **Secure multiparty computation:** a technique for splitting up computational tasks among multiple actors so that no one party has access to all the data.
- **Trusted execution environments (TEEs):** secure processing on the micro-processor itself, TEE allows for the safe un-encryption of data, the performance of functions on it, and safe re-encryption.

Secure computation can help enable federated computing and learning capabilities that could have a profound impact on medical research, among other things. Federated learning is the ability of a model to learn from data in a privacy-preserving way, often by "sending compute to data".[3] These techniques are already in use. For example, Google's predictive typing model learns from each user's behaviour by being sent to the user's phone. In this way the model learns locally, and the data never leaves the phone.

While, as previously mentioned, these technologies have nothing to do with blockchain, they are often associated with blockchain-based use cases, where the blockchain is for instance employed to orchestrate and provide an audit trail of the interactions between users and those using the data. We will return to privacy-preserving computing techniques often during this paper.

3 This is often achieved by sending an AI model to a data set to train, instead of sending the data to the model. In this way the data never leaves the control of the data owner. The AI model will emerge with its learnings, but no reference to the data. We cover this subject in more detail in our paper Convergence of blockchain with AI and IoT, EU Blockchain Observatory and Forum, 21 April 2019.

Data sovereignty: Blockchain for patients and individual health

THE HEALTHCARE DATA CHALLENGE FOR INDIVIDUALS

Of all the different types of personal data that exist, health data is among the most important. Information about our physical and mental health, as well as our biometrics, is of course highly private and needs to be guarded well. This information is very important: our health data helps us understand ourselves better and gives us tools to play a more active part in our healthcare and in staying healthy. It is also useful: health histories are key to successful cures. Finally, it is extremely valuable: our health data is highly sought after by researchers, insurance companies and others, who are often willing to pay for it.

Yet despite this value, most of our health data does not belong to us. When we go to the hospital or a doctor, that data is recorded in an electronic health record (EHR) that almost always belongs to the doctor or the organisation. We therefore have to rely on that doctor or organisation to keep it safe, something the health industry has struggled to do.[1] Because data is in silos, it is difficult to get a full overview of our information, which is a problem both for us and for those who would help us get well. And to the extent our data can be monetised, it is someone else gaining that value.

1 For the situation in the US, see 2019 Healthcare Data Breach Report, HIPAA Journal, 13 February 2020.

Below we look at some ways blockchain can help improve the way individuals can manage and make use of their personal health data.

SELF-SOVEREIGN IDENTITY FOR PERSONAL HEALTH INFORMATION

Applying the self-sovereign identity paradigm we alluded to above to personal health information would allow patients (and healthy people) to store their health data themselves without relying on a third party. This could be the actual data as well as attestations and verifiable credentials, like health passports, that would be under the user's control. In essence, individuals would be in charge of their own, comprehensive electronic health records.

This could have many advantages. It would give individuals more control as they would be in a position to grant or deny access to the information as well as decide which information to reveal in which context, and which not. Selective disclosure can help individuals keep their health data much more private, as only the information needed is shared. Data that is compartmentalised in this way is also harder to use in combination with information gathered elsewhere to, for instance, construct profiles. Self-sovereign health data would make it easier for

individuals to aggregate all their health-related information themselves. This can be lifesaving in an emergency, as it provides a means for accident victims to share their health histories quickly with first responders,[2] and it can save a great deal of time, effort and cost when, for example, being admitted to a hospital, or changing doctors.

Aggregate health data can help individuals take more control of their health, either by designing better strategies to stay well, or by helping with diagnoses and facilitating personalised medicine. By adding lifestyle and other data, individuals can provide proof of healthy habits, potentially qualifying for incentives like reduced insurance premiums. Decentralised identities and data stores are also safer than centralised ones in certain respects. A huge centralised database is a honeypot for hackers. Hacking individual data stores is seldom worth the cost.

There are risks and challenges too. While decentralised identity is generally safe from hackers intent on large hauls of data, it is less safe against misuse or mistakes by individuals. The cryptography that underpins much of this is unforgiving; a lost private key means permanent loss of data. Therefore key management and data recovery techniques have to be available and well thought through. Self-sovereign health data will require data standards and frameworks, for example to answer the question of what levels of assurance are acceptable in a given situation. This will require solving many legal and regulatory issues, for example around privacy or what legal grounds are necessary to allow access when a patient is unresponsive. Justt as important in a decentralised system is the question of authenticity of data. When individuals curate their own health records, how can we ensure this data is correct and complete?

PATIENT-MEDIATED HEALTH DATA EXCHANGES

Through the process of tokenisation, blockchain can make it possible to package data in discrete units that can be sealed and then safely transferred. This makes it theoretically possible for individuals, once they have aggregated their personal health data, to "take it to market" if they want to, for example in blockchain-based health data exchanges.

Such markets would make it possible for individuals to share, rent or sell some of their personal health data to interested parties. These could be pharmaceutical companies interested in data for research or trials or AI companies looking to train models for diagnostic purposes. Using federated learning techniques, this could in theory be done in a privacy-preserving way, so that the data itself is never revealed nor leaves the possession of its owner. In many cases, companies or researchers will be more than willing to pay for this data, as procuring it an open data exchange may very well be less expensive than collecting it on their own. Yet health data exchanges need not be only for commercial purposes. They can also be used as clearing houses for individuals to share data freely (again, in privacy-preserving ways), for instance if they become aware of researchers working on a condition they suffer from. Such clearing houses could make it easier for individuals to profit from various incentives. For example, if you exercise regularly, an insurance company might be willing to offer you a reduced

2 Systems could conceivably be devised that would allow such sharing even in cases where the victim is not responsive.

premium provided you can prove your claim.

Such data markets could be a boon not just to individuals but also to society as a whole. Incentivising the sharing of data, whether for money or freely, would not only increase the amount of data available, it would make it easier to track provenance and so better judge the quality of that data.[3]

FROM HEALTH CONSUMERS TO HEALTH (AND WEALTH) PRODUCERS

Today, digital health is already patient-centric to a large degree. Decentralised health as we are describing it here would be far more patient-driven, which is a nuance, but a powerful one.

For instance, the ability to continuously aggregate health data information, control access to it, provide verifiable proofs of its accuracy, and so in effect create trustworthy self-sovereign health records, could have a great impact in promoting healthier lives and improving healthcare outcomes.

Self-sovereign health records would make it easier for individuals to collaborate much more actively with their physicians and other healthcare professionals in their own personal healthcare. Such records could also be used to encourage and facilitate value-based care models in which doctors are paid based on health outcomes, not treatments. Many doctors would welcome this chance to be compensated for keeping people healthy instead of just for curing them when they are sick, so this could make a huge impact.

Using blockchain-based tokens, for instance stable coins that represent fiat currencies, we could add a financial aspect to any rewards for good behaviour. Individuals could get paid for jogging regularly, with the proof being tied to their wearable fitness devices. Obviously, such scenarios would not be easy to implement, and privacy would be, as always, a concern. But blockchain does provide one tool to facilitate such platforms and turn health consumers into health and wealth producers.

3 We cover this idea of the correlation between data markets and increased data quality in more detail in our paper Convergence of blockchain with AI and IoT, EU Blockchain Observatory and Forum, 21 April 2019.

Data transparency: Blockchain in healthcare and life sciences

THE DATA CHALLENGE IN HEALTHCARE AND LIFE SCIENCES

Data provides the energy for the healthcare industry. Whether it is researching a new cure, fighting a pandemic, ensuring quality in a pharmaceutical supply chain, studying the efficacy of treatments, setting healthcare policy, or any of the myriad of other complex tasks involved in administering healthcare – from hospital admittance to insurance payouts – there is hardly any part of the healthcare system today that isn't data-driven.

The good news is that there is plenty of health data to be had. Hospitals, doctors, pharmaceutical companies, researchers, medical supply companies, wearable device manufacturers, healthcare organisations, government agencies, and individuals are constantly producing new digital data. The bad news is that, despite its ubiquity, this data can be hard to find or share. Today healthcare data is often locked in silos, walled off by technology either designed to keep it locked away or, through lack of interoperability, has that unintended effect. Considering the value of data, many healthcare industry participants like pharmaceutical companies have powerful, and perfectly legitimate, incentives to hold on to their data and intellectual property tightly. As we have seen, individuals have incentives to guard their personal health data too, and personal health data is often covered by legislation and regulations intended to ensure these protections.

Below we look at some ways that blockchain could be used to meet the healthcare industry's data challenge.

BLOCKCHAIN FOR MEDICAL RESEARCH AND DIAGNOSTICS

Blockchain can play a role in medical research and diagnostics in many different ways.

Blockchain and the Internet of Medical Things. Along with being data-dependent, the healthcare industry also relies heavily on a myriad of network-connected devices, often referred to as the Internet of Medical Things (IoMT).[1] As these devices are constantly sending out information, the challenge is to ensure that this data is authentic and to make it as accessible as possible while keeping it secure.

In our paper on the Convergence of Blockchain with AI and IoT,[2] we discussed how blockchain can work with IoT in general to accomplish such ends by a) providing a means for network-connected devices to seal and package data at source, provide it with metadata like timestamps and device IDs, and then upload it to blockchain-based platforms, and b) by securing the provenance and authenticity of instructions that are sent from a platform to an IoT device/actuator, so the device can be sure

1 Like IoT in general, the IoMT is a quickly growing and highly valuable sector. See IoT Healthcare in 2020: Companies, devices, use cases and market stats, Business Insider, 13 February, 2020.
2 Convergence of blockchain with AI and IoT, EU Blockchain Observatory and Forum, 21 April 2019.

DATA TRANSPARENCY: BLOCKCHAIN IN HEALTHCARE AND LIFE SCIENCES

that the commands it receives are real. Such capabilities could be very useful in healthcare settings to help ensure the authenticity of IoMT-generated data, help in its distribution and re-use, and also help to more securely control devices remotely.

Decentralised data exchanges for life sciences. Above we talked about patient-mediated data exchanges. We can also imagine broad-based data exchanges for life sciences industries. In fact these could be one and the same, or could interoperate with each other. Such exchanges could be built by industry consortia, and provide a platform for data producers like pharmaceutical companies, hospitals, health insurance companies, equipment manufacturers, and government agencies to upload their data for sale, rent or sharing. Here too incentives could be monetary or non-monetary, depending on the use case and individual situation.

Such large-scale data markets, particularly if data could be traded in both transparent but IP-protecting ways, could be a boon to pharmaceutical companies and researchers as a reliable source of big data. They could also open up access to large data sets to independent researchers, entrepreneurs and smaller companies, helping to drive innovation. Similarly, they could be useful in public health monitoring by providing authorities access to dynamic data sets (ideally in privacy-preserving ways) that would allow them to spot trends quickly.

Along with data markets, we could imagine large-scale, tokenised markets for research results and health knowledge. We have written elsewhere of how blockchain could help facilitate decentralised markets for trained AI algorithms, making the results of AI analyses more readily available to a wider audience. We could imagine something similar in healthcare contexts. We could also see blockchain potentially as the basis for broad-based, public healthcare knowledge bases, where the blockchain could provide trust in the form of provenance information or access control, as well as act as a (micro)payment platform.

Blockchain for clinical trials. Developing new drugs is an expensive proposition, costing on average over one billion euros. It is also an uncertain one, with a one in 1,000 chance of success. Clinical trials are an important element of the process, but they too can be expensive and difficult to run. Organisers of clinical trials must deal with the problem of data silos as well as a heavy compliance burden. The process of recruiting participants is particularly expensive and time consuming, often involving visits to up to a hundred different healthcare facilities to discuss the trial and find suitable candidates, each of which acts as a gatekeeper to their patients.

These problems might be addressed, among other ways, through a blockchain-based global patient database that could serve as a clearing house for candidates for clinical trials. This would have to be created using privacy-preserving methods; but given sufficient control and oversight, and rich enough metadata, it could provide a comprehensive overview of the healthcare landscape that could make it much easier for pharmaceutical companies to identify suitable patients and potentially recruit them directly. This could lead to better designed trials as well as make it easier to set up remote trials in which patients connected to IoMT devices could monitor themselves and deliver their own clinical data, potentially in real time. Furthermore, and

again with an eye to the privacy-preserving and secure computing techniques we have already touched on, this could enable re-use of data from clinical trials in subsequent trials.

Blockchain for the medical supply chain. As we discussed in detail in a separate thematic report on the subject, supply chain is one of the most important use cases for blockchain as blockchains are excellent tools for tackling track and trace challenges. Pharmaceutical and medical equipment supply chains are complex, global endeavours. Safety is a major concern and these industries are under intense pressure to fight counterfeit products and to check abuse. Blockchain-based supply chain platforms could help fight counterfeit medicines and parts for medical devices by providing reliable provenance information as well as monitoring along the chain (often in conjunction with IoT sensors). They could also help improve supply chain efficiency and lower costs. This could contribute to public safety as well, by making it easier to trace defective materials or contaminated chemicals and drugs. This is important in keeping supplies safe, but also in the "aftermarket", for example in recalls or issues with medical devices in use by patients.

BLOCKCHAIN FOR THE HEALTHCARE INDUSTRY

Blockchain can be used in the healthcare industry as well. Most of these use cases have to do with efficiency gains and cost savings and are similar to blockchain use cases in other industries. They include:

- **Point of care.** Self-sovereign health data, if it could be accessed quickly, could be used to give first responders access to critical health records in an emergency. Individuals could, for example, grant rights for recognised services, like paramedics, to access that data if they are not able to themselves due to injury or illness. Anyone who has gone to a new doctor or been admitted to a hospital will also be familiar with the administrative burdens involved. Self-sovereign health records could help simplify admissions procedures by allowing patients to easily grant access to their relevant information. The ability to grant access to full medical records could help streamline care as well as insurance procedures.
- **Administration of healthcare services.** Like many industries, the healthcare industry struggles with complexity, outdated infrastructure and processes, security issues, inefficiencies and compliance burdens, all of which drives up costs. Blockchain could be employed to build shared infrastructures to address these issues. Such platforms could help reduce administrative friction by making it easier to share records and so reduce redundant record-keeping and processes as well as errors. Blockchain-based document sharing libraries could greatly reduce overhead while increasing trust in the authenticity of electronic documents. Blockchain could help organisations reduce costs by streamlining compliance processes, including, potentially, by having regulators or oversight bodies participate in the platform and monitor compliance themselves, saving effort on both sides.[3] These capabilities could also be used to improve revenue cycle management for

3 The benefits of having regulators "on chain" are a topic of discussion in many sectors, for example in the financial industry. See Blockchain for Government and Public Services, EU Blockchain Observatory and Forum, 9 December 2018.

healthcare organisations, from payments through to claims management and fighting insurance fraud. The potential of blockchain for this part of the healthcare industry has already been recognised, and there are a number of large-scale consortia in Europe and the US that have been formed to tackle these issues.[4]

- **Distribution of healthcare services.** We can also imagine combining all of the above capabilities to create new models for the distribution of healthcare services. This could take the form of a large-scale, tokenised ecosystem for healthcare that brings together all players in the system on one platform, from healthy individuals and those requiring care to healthcare workers, doctors, healthcare organisations, hospitals, pharmaceutical companies, insurance companies, and governments. Being comprehensive, such a platform could act as a multiplier for the benefits already outlined, such as more efficient and transparent processes for the registration and handling of the services themselves, better tools to incentivise desired behaviours; or the possibility of easily applying data analytics and artificial intelligence to improve both services and healthcare strategies.[5]
- **Health statistics and population monitoring.** Although we have touched on it above, it bears repeating that the general ability of blockchain to "free" data from silos could help greatly in public health monitoring contexts, allowing authorities to develop a very detailed, accurate and timely view of population health trends and issues.
- **Preventive care, after care and value-based health.** Decentralised health data and tokenised data markets and incentive schemes can also help in the important areas of both preventive and after care. It is well known that the best way to bring down healthcare costs is to keep people healthy as much as possible. Paying people with a tendency for diabetes (for example) to change their diet is likely to be far less costly to the individual and the system than to treat the disease. Blockchain-based platforms could help both in aggregating trustworthy data and facilitating payments. Large-scale, privacy-preserving health data platforms could help researchers find out what kinds of activities and preventive care strategies provide the best return on the investment. A similar thing could be done with after care through tracking the results of treatments and therapies, thereby supporting value-based healthcare models.[6]

BLOCKCHAIN FOR HEALTHCARE WORKERS

In this section we explore some use cases for blockchain in supporting medical professionals.

Professional training. Education is another recognised blockchain use case. As discussed in the academic paper on the subject prepared for the Observatory by the University of Southampton,[7] blockchain's attributes of verifiability and trust as well as decentralisation

4 See Aetna, Anthem, Health Care Service Corporation, PNC Bank and IBM announce collaboration to establish blockchain-based ecosystem for the healthcare industry, IBM News Room, 24 Jan, 2019.
5 See Blockchain Revolution in the Governance of Nations and Cities, Stefan Junestrand, 19 March 2019.
6 What Is Value-Based Healthcare?, NEJM Catalyst, 1 January 2017.
7 Blockchains and Education, Dr Allan Third, Dr Kevin Quick, Mr Chris Valentine, Mrs Michelle Bachler and Prof John Domingue, EU Blockchain Observatory and Forum, 5 December 2019.

can be used to reduce the costs and simplify processes around the handling of diplomas and professional credentials, as well as foster new learning paradigms through better tools for collaboration and disintermediation of education providers. Whether or not such approaches can be fruitfully applied in medical training, or in the training of other healthcare workers, remains to be seen. Yet in a field as knowledge-intensive as healthcare, if blockchain makes inroads in education, we can expect these to have applications here as well.

Professional credentialing. When a doctor changes hospitals, moves to another region, or is temporarily employed as a stand-in (locum tenens), it can be difficult to have credentials transferred or verified. Blockchain could be used to set up decentralised accreditation regimes on the self-sovereign identity model. Under this approach, doctors could keep verifiable medical credentials themselves, and use them as needed. The need for this has been recognised, and there are already blockchain projects addressing it.[8] More broadly, the EU has recognised the value of blockchain in credentialing, having named Diplomas as one of the use cases for the European Blockchain Services Infrastructure (EBSI).[9]

Grassroots communities and DAOs for doctors.[10] The medical profession is an ancient and venerable one, but in the modern era the profession has become highly institutionalised. Doctors today are more likely to work for large institutions and clinics, on a salary, than be in private practice. As a result, their places of employment often do not necessarily represent their needs, but focus naturally on the organisation's priorities first. And while there are many professional medical organisations, these tend to be highly centralised too. Blockchain could be used to balance this tendency with decentralised platforms and services for doctors and healthcare workers. Blockchain could be used as a basis for community-driven organisations for healthcare professionals. These could provide common services, like legal services or malpractice insurance, and serve as grassroots lobbying organisations. With blockchain it could be easy to set up tokenised, decentralised marketplaces for doctors and healthcare workers to share knowledge and/or services among themselves, or in which providers could offer services. Thanks to tokenisation, such marketplaces could feature monetary or novel, non-monetary incentives like reputation or utility tokens. Blockchain could also be the basis for professional social media platforms for healthcare workers. Blockchain could be used to support decentralised governance for such a platform, allowing the application of novel governance tools like quadratic voting, quadratic finance and liquid democracy all the way through to decentralised autonomous organisations such as a DAO for doctor.

TOWARDS A UNIVERSAL MEDICAL BLOCKCHAIN

Up to now we have discussed how blockchain can be used to decentralise various parts of the healthcare system. How far can this process go? We could imagine the various elements discussed so far coalescing over time into larger and larger platforms and ultimately into some form of a global medical blockchain. For the purposes of this thought experiment,

8 See for instance ProcredX, Intivahealth and Blockcerts.
9 European Blockchain Services Infrastructure.
10 This section is indebted to ideas proposed by Dr Alex Cahana, Chief Medical Officer of ConsenSys Health, in an interview for this paper. For the DAO for Doctors see Out Of 126 Healthcare White Papers We Analyzed, One Stood Out. Part 2, Alex Cahana, 6 January 2019.

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we assume all the privacy-preserving aspects we have touched upon, such that this universal medical platform is a user-centric, secure and globally shared health resource controlled by its users, whether patients, healthcare professionals, insurance companies, pharmaceutical companies or governments.

Designing such a complex platform from scratch would be a daunting engineering challenge. Yet if it is based on decentralised technologies it wouldn't necessarily need to be designed and built using traditional methods. Instead, it could take advantage of the scope that decentralised technologies give for systems to self-organise and interoperate to grow organically over time. A range of small, discrete decentralised platforms could merge over time into ever larger structures. While this may seem far-fetched today, in 25 years' time blockchain and other emerging technologies may have indeed matured enough to make something like this viable. Only time will tell.

Blockchain and the fight against COVID-19

As this thematic report was being prepared, the world was hit by the COVID-19 pandemic. The crisis has stretched healthcare services in many countries to the limit, stalled economies, shut down social life, and caused a strain on global supply chains and many other sectors. It has also inspired a wide range of responses, both by the many heroic doctors and healthcare professionals on the front lines of the pandemic, as well as on the part of authorities, the private sector and individuals intent on fighting this scourge. For its part, the blockchain has responded with a wide array of proposals, hackathons and projects aimed at accelerating blockchain use cases that might help in the effort. Many of these, unsurprisingly, reflect the issues and use cases that we have been discussing in this paper.

Medical supply chains. COVID-19 has caused a major disruption in global supply chains, including medical supply chains. This has hurt response efforts. Supply chain disruption has caused shortages of the personal protective equipment (PPE) needed to protect doctors and nurses on the front lines treating patients. Other medical equipment, like testing equipment, ventilators and essential anaesthetics, are in short supply in many areas as well. Many of these supply chain issues are related to the fact that large portions of global supply chains rely on manual processes, paper documents and "wet" signatures (made with ink), processes which can be hard to follow in times of lockdown.[1] One benefit of blockchain for supply chains is that, by providing trust in digital documents, automating processes and agreements, and facilitating electronic payments, they provide a clear basis and catalyst for digitalisation. They also tend to add transparency to supply chains, making it easier to locate items along the chain and spot bottlenecks. Crucially, this can make it easier to fight fraud and counterfeiting along the chain. While building blockchain-based medical supply chains on short notice to battle this pandemic is not likely to be feasible, we have seen blockchain-based efforts to prove authenticity of items being shipped today.[2]

Privacy-preserving contact tracing and health data sharing. While one of the best ways to fight the virus, many believe that the universal tracking of the movements of all members of a population can set a dangerous precedent. There are also concerns about the widespread sharing of other kinds of health data during the crisis. For example, test results could be used as the basis for issuing immunity passports, but if these are centrally maintained that information could potentially be misused or subject to hacking. Using the privacy-preserving technologies discussed in this paper in conjunction with blockchain platforms could make it possible to bring both privacy and transparency to efforts to monitor populations and share COVID-related health data, and there have been several blockchain-based solutions proposed to do this.[3]

1 Supply chains have been upended. Here's how to make them more resilient, WEF, 6 April 2020

2 See Blockchain to Authenticate Coronavirus-Response KN95 Face Masks From China, CoinTelegraph, 9 April 2020.

3 See Coronavirus-Tracking Apps Take Different Approaches in Keeping People Safe, Cointelegraph, 11 April 2020; CENTOGENE and Ubirch Create Secure Blockchain Solution for the Successful Fight Against COVID-19, dgap.de, 17 April 2020; and the MiPasa project.

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Mitigating the negative economic effects of lockdowns. To fight the pandemic, authorities in countries around the world have issued rest-in-place orders. These lockdowns have caused whole economies to grind to a halt, threatening businesses and leading to mass lay-offs in many fields. While blockchain cannot restart an economy, blockchain-based platforms could help mitigate the effects of lockdowns. For example, stable coins or tokenised fiat currencies could make direct distribution of stimulus payments straightforward, fast and unbureaucratic. Ideas have also been floated for social-distancing tokens and other means of using cryptocurrencies to encourage individuals to behave safely and responsibly.

Help with COVID research. Blockchain is also being used in different ways to support COVID-related research. To take a few examples: in the US, the largest miner on the Ethereum blockchain has redirected the processing power of 6,000 of its specialised mining chips[4] to support Stanford University's Folding@home[5] research project. Another project is looking at using blockchain and AI to develop self-testing methods.[6]

Social response. The pandemic has also been a strain on society. Blockchain-based approaches have been proposed to support privacy-preserving approaches to social distancing,[7] speed up insurance claims payouts during the crisis,[8] use cryptocurrencies for donations to organisations fighting the disease,[9] and to fight COVID-related fake news.[10]

INATBA COVID Task Force. The European blockchain community has also become directly involved, among other things through the INATBA COVID Task Force, which is working to address governmental, social and commercial challenges caused by COVID by analysing and presenting blockchain-based solutions to government.

4 Thousands of These Computers Were Mining Cryptocurrency. Now They're Working on Coronavirus Research, CoinDesk, 19 March, 2020.
5 Folding@Home Update on SARS COV-2 (10 March 2020), Folding@Home, 10 March 2020.
6 Blockchain and Artificial Intelligence Technology for Novel Coronavirus Disease 2019 Self-Testing, MDPI, 1 April 2020.
7 German Startup Pitches Decentralized ID for Prescription Pickup During COVID-19, CoinDesk, 20 March 2020
8 Chinese Insurers Tap Blockchain to Speed Coronavirus Payouts, Yahoo! Finance, 11 February 2020
9 Italian Red Cross Builds COVID-19 Medical Post With Donated Bitcoins, CoinTelegraph, 8 April 2020.
10 Similar authenticity concerns led to the development of a blockchain news certification platform by an Italian news company.

Conclusion and recommendations

We have seen that blockchain has a lot of potential in the healthcare industry. This is not surprising as many of the issues facing healthcare relate to the kind of data management and track and trace problems that blockchain is well suited to address. Policy makers looking to support blockchain in healthcare can do a lot simply by supporting blockchain in general. Many of the more general recommendations that we have made in previous works, for example our reports on Digital Identity, GDPR, Legal Recognition of Blockchains and Smart Contracts, Supply Chain and the Convergence of Blockchain with AI and IoT, would apply to the specific use case of blockchain and healthcare as well.

Adding to those, we would make the following more specific recommendations.

1. Support healthcare-based blockchain consortia and public/private partnerships.

The recently launched PharmaLedger[1] consortium, which is a public/private partnership under Europe's Innovative Medicines Initiative (IMI), aims to build a blockchain-based platform and reference use case implementations for medical supply chains, clinical trials and health data. Such efforts can be very effective and policy makers should look to develop and support more such efforts.

2. Support blockchain-based healthcare projects.

The INATBA COVID Task Force has shown how public/private partnerships can react quickly in a healthcare crisis. By leveraging INATBA and other European blockchain organisations, including the Observatory, the EU could help support blockchain-based healthcare projects and companies, and so develop the ecosystem.

3. Healthcare as part of EBSI.

Among the initial EBSI use cases are both support for self-sovereign identity, academic credentialing and trusted data sharing across borders (notarisation). As the EBSI continues to expand, we recommend that healthcare-specific use cases be considered as well.

1 https://pharmaledger.eu/

Appendix – Blockchain Terminology

What is a blockchain?
Blockchain is one of the major technological breakthroughs of the past decade. A technology that allows large groups of people and organisations to reach agreement on and permanently record information without a central authority, it has been recognised as an important tool for building a fair, inclusive, secure and democratic digital economy. This has significant implications for how we think about many of our economic, social and political institutions.

How does it work?
At its core, blockchain is a shared, peer-to-peer database. While there are currently several different kinds of blockchains in existence, they share certain functional characteristics. They generally include a means for nodes on the network to communicate directly with each other. They have a mechanism for nodes on the network to propose the addition of information to the database, usually in the form of some transaction, and a consensus mechanism by which the network can validate what is the agreed-upon version of the database.

Blockchain gets its name from the fact that data is stored in groups known as blocks, and that each validated block is cryptographically sealed to the previous block, forming an ever-growing chain of data. Instead of being stored in a central location, all the nodes in the network share an identical copy of the blockchain, continuously updating it as new valid blocks are added.

What is it used for?
Blockchain is a technology that can be used to decentralise and automate processes in a large number of contexts. The attributes of blockchain allow for large numbers of individuals or entities, whether collaborators or competitors, to come to a consensus on information and immutably store it. For this reason, blockchain has been described as a “trust machine“.

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The potential use cases for blockchain are vast. People are looking at blockchain technology to disrupt most industries, including from automotive, banking, education, energy and e-government to healthcare, insurance, law, music, art, real estate and travel. While blockchain is definitely not the solution for every problem, smart contract automation and disintermediation enable reduced costs, lower risks of errors and fraud and drastically improved speed and experience in many processes.

Glossary

The vocabulary used in the context of blockchains is quite specific and can be hard to understand. Here are the essential concepts you should know in order to navigate this breakthrough technology:

- **Node:** A node is a computer running specific software which allows that computer to process and communicate pieces of information to other nodes. In blockchains, each node stores a copy of the ledger and information is relayed from peer node to peer node until transmitted to all nodes in the network.
- **Signature:** Signing a message or a transaction consists in encrypting data using a pair of asymmetric keys. Asymmetric cryptography allows someone to interchangeably use one key for encrypting and the other key for decrypting. Data is encrypted using the private key and can be decrypted by third-party actors using the public key to verify the message was sent by the holder of the private key.
- **Transaction:** Transactions are the most granular piece of information that can be shared among a blockchain network. They are generated by users and include information such as the value of the transfer, address of the receiver and data payload. Before sending a transaction to the network, a user signs its contents by using a cryptographic private key. By controlling the validity of signatures, nodes can figure out who is the sender of a transaction and ensure that the transaction content has not been manipulated while being transmitted over the network.
- **Hash:** A hash is the result of a function that transforms data into a unique, fixed-length digest that cannot be reversed to produce the input. It can be viewed as the digital version of a fingerprint, for any type of data.
- **Block:** A block is the data structure used in blockchains to group transactions. In addition to transactions, blocks include other elements such as the hash of the previous block and a timestamp.
- **Smart contract:** Smart contracts are pieces of code stored on the blockchain that will self-execute once deployed, thus leveraging

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the trust and security of the blockchain network. They allow users to automate business logic and therefore enhance or completely redesign business processes and services.

- **Token:** Tokens are a type of digital asset that can be tracked or transferred on a blockchain. Tokens are often used as a digital representation of assets like commodities, stocks and even physical products. Tokens are also used to incentivise actors in maintaining and securing blockchain networks.
- **Consensus algorithm:** Consensus algorithms ensure convergence towards a single, immutable version of the ledger. They allow actors on the network to agree on the content recorded on the blockchain, taking into consideration the fact that some actors can be faulty or malicious. This can be achieved by various means depending on the specific needs. The most famous consensus algorithms include proof-of-work, proof-of-stake and proof-of-authority.
- **Validator nodes:** Validator nodes are specific nodes in a network that are responsible for constituting blocks and broadcasting these blocks with the network. To create a valid new block they have to follow the exact rules specified by the consensus algorithm.

Learn more about blockchain by watching a recording of our Ask me Anything session.