

Blockchain Technology in Healthcare

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Abstract: A big portion of data that are produced by various digital ecosystems has met a lack of interoperability on the line between applications, data streams and predictability in the healthcare. The new technology approach in the distributed messaging and Blockchain became a key component of many healthcare technology stacks and can derive real-time data streams as valuable and scalable enough to enable real-time healthcare predictive analytics. Besides, ingesting data streams from various sources from patterns of data can extend healthcare trend analysis to the higher level of prediction, accuracy and improve models that suffer from complex and long-running analyses. A better response, lower availability requirements and unifying predictive modelling will accelerate healthcare interoperability and thus increase the accuracy of diagnoses, put the evidence-based medicine (EBM) in the right direction and other healthcare benefits which increase optimum outcomes and quality.

1 INTRODUCTION

1.1 Step Forward into Healthcare Interoperability with IoT Distributed Data

From the very beginning of information technology usage in healthcare, the data producing was always in the matter. Either, the simple patient personal records or various medical treatment descriptions, it always needs to be a countable amount of data in digital form.

On the other hand, overall technological advances have made medical devices become smarter and, therefore, the ability to produce a higher amount of data. In addition, computer networking and the Internet have enabled data exchange both in the local (hospital) and in the Geo-global environment. Besides medical devices, most of the power supplied devices around us became also smarter. Vehicles, trains, planes, lights, watches, parking garages... get a common denominator in the world of smart devices and it is called Internet of Things (IoT) - with the basic idea of connecting all devices to each other. The IoT can be understood as the natural evolution of the web as it merges information technology and many other operational technologies. It links more than ordinary

life devices – it connects all that devices containing such a sensors collection. By connecting and networking a common thread is IoT based machinery that uses data streams as its fuel.

The digital revolution led by IoT (i4.0) has not bypassed the sphere of the healthcare.

Considering all the verticals in healthcare, regardless of whether new technologies are applied - in a hospital environment or in personal use by patients, it is evident that they are the part of the change in the healthcare industry at all – from the much based IoT eHealth wearable devices up to sophisticated medical sensors.

Leveraging by new trends, the healthcare is going to be revolutionized in methods where every patient comes to the ability to interact with any subject of new technology and also to each other. From that point of view, the healthcare institutions are already suffering on how to share data between different platforms. Another weak point is an inability to hold a secure data at the physical and logical level. Blockchain appears as a promising - near future answer to this data integrity dilemma. It allows better collaboration on data level between payers and providers adopting the principle of secure store of electronic medical records. If it is true, the providers can count of a higher probability in

diagnosis accuracy by feeding healthcare information systems with tons of data.

However, all of us who are participants in the newly created technological era sometimes wonder what is actually happening, where is all this leading? Is there a particular benefit that is focused on increasing the quality of health services and patients themselves will become mere consumers of innovative achievements?

Seen from the side of the patient, who is participating in the innovative world and the primarily intended benefit is enormous.

Availability of various sensors and diagnostic elements integrated into mobile communication devices to quickly and simplified patient contact your physician and clinical centers. This mode has shortened the path to obtaining a timely diagnosis and simultaneously helps the patient.

Not taking into account all the technological and technical obstacles such as lack of interoperability and different standards in terms of integration, we come back to the starting point of view of that unique element which is concomitantly building block or the end product and that's the - data. In our case, these are the data of the patient. Whether this is just a basis for the identification of a patient in the system (EHR) or used as an expanded set of data in the analysis and prediction of disease and diagnosis, the data is potential, high risk factor. Seen from the patient as a consumer, if its data is vulnerable - and he himself is at risk.

In the process of data collection from points of origin to its final destination, securing the data is required under the HIPAA compliance. But in practice, it turned out that due to deficiencies in the security standards should lead to greater involvement of the IT sector in the field of data protection and increased interoperability.

A new technology such as Blockchain is very promising in terms of increasing interoperability, security transfer and exchange of information. As the information is distributed over the network(s), Blockchain especially has become as a solution to establish the trust of all the factors in the world of digital healthcare. Also, all challenges addressing the security of protected health information (PHI) and HIPAA compliance has an opportunity as a solver tech by using Blockchain encrypted data and its validated replication over the network.

From another standpoint, the healthcare data are very complex. They are built of various data formats, images and videos, sometimes non - structured data.

All that is the representation of a single health record of the patient. Such patient records, time-stamped and signed by using a private key under the Blockchain can be distributed without losing data integrity and make the stairway to deep learning, a new technology based approach in healthcare data analysis and prediction.

Putting them together, the principle of secure, valid and distributed health information is likely to be closer to goal of the healthcare interoperability and precision medicine with promise to unlock access to all population health data.

In addition, the caregivers, community of people, doctors, patients, insurances and all other health information consumers, by being a part of Blockchain reduces a fraud in healthcare payments.

2 CONCEPT

2.1 Blockchain Itself

There are various definitions that try to explain the background of Blockchain technology in a simple way. One of the most commonly used definition states that a Blockchain is a distributed system (distributed ledger) divided or in other words, decentralized into blocks which are connected with nodes. Blockchain uses mathematical models for the distribution of encrypted information through the chain of blocks, making them safe and transacted at the real time. Some of the basic terms should be considered at first to be able to understand the definition.

Distributed system is for a long time already in the computer terminology and represents an earlier definition of the computer network where they are separate individuals, i.e. computers spread on a geographical area. Nowadays, is now much more used as a system of multiple autonomous processes, i.e. computers (nodes) that communicate with each other by passing messages.

Decentralized means that there is no central point or entity that takes care about of transactions, identities and no data are held centrally.

The **Block** itself simply represents a file and it could be a text file (like book chapter), image, video sample, spreadsheet or any kind of structured data that consists records which are storable and readable by the machine.

The blocks are interconnected with **nodes** (hubs) creating a chain like a process and govern the transmission of information.

Transactions are actually information, i.e. data transmission that referred to one block. They are message broadcasting based system. By the simple meaning, the transaction is single operation over one node and as the nodes is able to communicate and transfer the data from one node to another across the network.

During this transmission process, each node acts as a central point and is able to generate and digitally sign the transaction. Then, as the nodes connect each other in a peer-to-peer network, each node has to verify incoming transaction independently for its validity, compliance and conflicts with peers. All these need to be digitally signed and tested so the transactions that passed the verification process enters the memory pool, a local list of the node's that are still provisionally marked as unconfirmed transactions. Later, they are forwarded on to its peers. All those transactions that are rejected are placed in the orphan pool - a temporary holding area.

One more rule that makes data transmission or transaction successful is described as cryptographic hashing. Each block of data has to be cryptographically hashed using the SHA-256 cryptographic hash algorithm on the header of the block. The header also contains the hash of the parent block. To complete the linear list of blocks and to establish a sequence, each block contains the hash of its parent and this way, creating the chain backing all the way up to the first block ever created. This first block in the chronology is also called genesis block. The simplified Blockchain is represented in Figure 1.



Figure 1: Simplified Blockchain.

Each block in the Blockchain is linked with the parent (previous) block of data stored in the header: timestamp (date-time) and origin.

2.2 Public vs Private Blockchain

The Blockchain is a public ledger. From that view of the authority, as there are many parties involved in transactions sharing the data headed by cryptographic keys, Blockchain can be public or a private. There is a big difference depending on which technology you need. It is also depending on the principle: Do not allow anyone to write to your

Blockchain or to someone known and thoroughly tested participant.

The first one, **public**, is the one about the people always meaning by talking about Blockchain and means actually that anyone, without permission which is granted by another authority, can read or write data. This one is also known as permission-less Blockchain. It has a greater possibility of compromising security while permission to Blockchain can be controlled easily.

The **private** Blockchain is the second one and obviously most popular. It is a permission based Blockchain where participants are known. They are trusted across their industry group or for example group of company and many of the permission mechanisms are not needed. In some cases, they are replaced by using legal contracts.

The issue of private versus public Blockchain leads to another moment of concern in the implementation of this new technology. First of them is criticism on top of vulnerability. Soon or later someone will find a hole in the coding loop of smart contracts. Such already happens in June 2016. This or similar should be overridden if a majority of validators follows the rules and produce stronger (also cheaper) immutability such one is resulted by using the private Blockchain. Besides, use of a private Blockchain shall become a more accessible to the general public. As far as the both or one satisfies main principles of data immutability, preserving smart contracts vulnerability and anonymous information during the transactions by agreement with authentication, it will be useful and acceptable.

2.3 Smart Contracts

Since we are talking about transactions between two entities it is necessary to have a simple rule that will establish the trust among them. As the transaction is digitally signed, the trust rule should also be in a digitally trusted form. Then, we have a **smart contract** – a form of the computer program (pre-written logic) that helps us to convert certain conditions in the valuable outcome. Outcomes are able to be stored and replicated across distributed system, executed over nodes and result in a change / update the state of digital asset.

Simple words description, smart contracts are little computer programs that execute in way represented in Figure 2.

From the current level of technology, smart contracts are programmed to perform simple functions and thus create agreements between



Figure 2: Smart contract.

parties. They can be peer-to-peer (P2P), person-to-organization (P2O) and person-to-machine (P2M).

2.4 Decentralized Database Consensus

Helping with the unique feature and the principles of the cryptography, the Blockchain has the potential to develop a database application consensus which is primarily decentralized. Besides, the secure authentication of transactions which is achieved by using hash codes in the record headers means of no possibility of the transaction duplication and thus no need of a central middleman/intermediary. This is the main point which breaks a centralized consensus paradigm. Avoiding the necessity of the central mediator there is no recorded replication of the previous transaction.

By using a decentralized scheme transactions got an ability to transfer authority as trusted across the network. This happens during transactions over the public block and its nodes by taking records regularly and sequentially – peculiarly creates a unique chain or Blockchain.

The consensus is more actively explained by the fact that only the header is available to the public. Only the creator has access to a private key (a distinctive fingerprint) and this is the only way how anyone can access the complete data.

Consensus shall be accepted as the starting layer of a decentralized architecture, foundation and as a prime rule protocol that drives the operation inside the Blockchain.

2.5 The Immutability

Basically, the principle of immutability is a something that could not be changed over time or it is unable to be changed. From the context of the security of the information / data that are stored on Blockchain, this is the topic of high importance. Using simple words of explanation: once written data to Blockchain, no one, also not even system / data administrator has no possibility to change it whatsoever.

This is beneficial. From one side, the data provider can prove that there is no data alteration from the data provider, the recipient can be sure that the data has not altered – the audits successful.

The immutability could also be relative in some specific use cases. For example: if someone sends a bulk email (the large list of recipients), from its perspective, the data are pretty immutable because if provider intends to change something or to delete an email, possible, but at the same time it is very hard as he needs to persuade everyone from the bulk list.

2.6 The Blockchain Proof of Work Principle

The proof of work is about a computational puzzle or hashing problems. Parties in a process of validating electronic transactions are repeatedly asked to solve-rerun hashing algorithm. Resolving the puzzle among hushing algorithm is very hard and estimates computational power but validating its solutions and also the block content is easy. This is the computational asymmetry which makes fraud so hard or better to say impossible.

This method is used for achieving a secure method of the value exchange. The result is no needs for a single – trusted authority in a process to clear and manage transactions as they are validated by individual nodes.

2.7 Interoperability Dilemma

A big portion of data that are produced by various digital ecosystems has met a lack of interoperability on the line between applications, data streams and predictability in the healthcare. The new technology approach in the distributed messaging and Blockchain became a key component of many healthcare technology stacks and can derive real-time data streams as valuable and scalable enough to enable real-time healthcare predictive analytics. Besides, ingesting data streams from various sources from patterns of data can extend healthcare trend analysis to the higher level of prediction, accuracy and improve models that suffer from complex and long-running analyses.



Figure 3: Interoperability dilemma on relation patient-physician.

A better response, lower availability requirements and unifying predictive modelling will accelerate healthcare interoperability (i14y) and thus increase the accuracy of diagnoses, put the evidence-based medicine (EBM) in the right direction and other healthcare benefits which increase optimum outcomes and quality.

2.8 The “Things” Collect & Exchange Data

The Internet of Things (IoT) is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction.

IoMT (Internet of Medical Things) - healthcare IoT - the collection of medical devices and applications that connect to healthcare IT systems through online computer networking.



Figure 4: Simplified IoT description.

Looking from the healthcare perspective, listed are some of the healthcare areas that can rely on IoT:

- Secured & Smart Healthcare Monitoring
- Remote patient (self) monitoring (RPM)
- Wearable health monitors (near future)
- Clinical decision support system (CDSS)
- Telematics & wireless medical telemetry services (WMTS)
- Telepathology
- Telepresence robotics
- Emergency notification system

2.9 Blockchain Use Cases for Healthcare

Nowadays, the information exchange is huge but the current infrastructures of healthcare information systems at all are inadequate to handle. Too many challenges around such as multiprocessor units, cloud technology and mobile application development are expressed by difficulties in handling on top of the DevOps & DEV CI and especially vulnerability. Blockchain comes into the

story as promising technology and has opportunity to do an impact on those challenges.

In the healthcare, usage of large files is part of almost each healthcare data transaction. Such files as imaging scans (PDF, TIFF...) estimates limitations. Where to store files, how to transfer and avoid changes or any kind of alteration by third parties. Blockchain solve this by using its distributed technology. With it, there is no need to store data on entirely chain. They have just to link with its hash or cryptographic numeric fingerprint. The transfer between parties can start without to alter anything in the source data or moving content to some central point to be accessible from other parties. The validation logic of Blockchain, the smart contracts on the Blockchain ledger deploy shared control so the transfer or blocks could not be duplicated or replicated from anyone across the network except the authorized nodes.

The Blockchain networks, i.e. private and permissioned such as Ethereum, can be maintained by official regulators (MHRA, FDA, CROs) and used by traditional clinical data management systems (CDMS). Cryptography and smart contracts allows trust in data integrity which allows medical professionals to make better decisions and have the potential to reduce patients risk from one side and efforts to reduce the data manipulation in the financial health services.

Master patient index (MPI) is a medical database. It holds electronic records from each patient registered at healthcare organization and includes information like patient name, DOB, race, gender, security number, place of residence...and another content that belongs to patient medical history. Besides, may include data on physicians and / or other medical stuff. MPI ensure the every patient is represented only once. This means also a constant demographic identification across the systems of hospital data. If the MPI is well organized, the institution that holds the data can ensure more accurate care for their patients.

Medical patient index is often created within electronic health systems (EHR). Usually the EHR has different vendors and its cause an irregularity of MPIs by accessing them from EHRs. Introducing an industry driven national patient identifier problem looks like a solved. But, not only EHRs access and use MPIs. There are also other healthcare systems that contain MPI, such a lab information systems, radiology and many vendor free computerized patient order entry software applications.

In many cases data between mentioned healthcare systems are mismatched or records are

duplicated – multiplied. Mismatches can be e.g. in the date of birth (DOB) as there can be as many different ways of DOBs as many systems are opting with MPI. Besides, the MPI data are centralized and verifying the data is mission impossible if there are many systems involved.

The Blockchain with its nature of decentralization has a possibility to solve this. If the Blockchain network incorporates MPI, the patient identification data were hashed to the ledger and content will remain unique, un-altered based on immutability of block contents inside the chain. All parties will deal only with header to access the MPIs but only authorized nodes (e.g. physician, lab technician) can view patient data and add content but only the owner has possibility to make any changes in hashed header. The mismatch or multiplied records could not be possible anymore as the smart contract do not allow that.

2.10 Potential Use Cases for Healthcare

Blockchain by its nature opens up an infinite number of possibilities for application in particular in the field of health care. The following topics are just an indication of those opportunities that are partially or fully implemented on the basis of the Blockchain health care.

- Fully privacy (100 %) peer to peer Blockchain network with possibilities to store and analyze patient health data. Possible are of use: clinical trials, precision medicine and research.

- Blockchain based patient tracking and identity assurance. This should include improved information exchange and validation. It is a strong healthcare interoperability issue.

- Healthcare objectives information exchange. Possible are of use: National healthcare initiatives to fulfill wide area health data interoperability.

- IoT Blockchain patient recorded outcomes measurement technology. Possible are of use: various area of medical diagnostics, patient management, clinical trials, pharma data management.

- Blockchain PHI – linkage protected health information with identities from verified credentials providers. Shall lower healthcare transactional costs and improve security.

- Blockchain pre-authorized payment. Possible are of use: clinical trials and prevention of counterfeit drug production.

- Blockchain predictive modeling. Possible are of use: improve health data interoperability across network of health institutions.

- Alternative payment models based on Blockchain by linking quality and value.

This clip is only the beginning of the development and application of technology that Blockchain is already showing remarkable for results in improving health care at the level of application of digital and innovative technologies. The development strategy is certainly on the side of these technologies in the near future.

3 CONCLUSION

3.1 Putting All Together – The Healthcare Interoperability

The purpose of this research was to determine if there is possible bridge solutions or such a technology platform that can put Blockchain and Deep Learning together in purpose of faster, more secure and reliable transfer of data between healthcare institutions and the human population in general as well as improving the preconditions that would lead to more reliable data analysis and thereby prediction in healthcare.

With its principle of non-centralized data collection and non-central database, but sharing and distributing data across networks by credentialed users with possibility to add and in the same time avoiding data alteration, Blockchain becomes a player in the information industry and in digital healthcare. From the early buzz of the healthcare it becomes lately a promising technology that is able to jump into healthcare interoperability story.

Many hopes and dreams about how and what this novel technology can accomplish to the healthcare data and its interoperability. Few of them are very important to basically push healthcare interoperability to next level:

Master Patient Index (MPI). Last year in a presentation at HIMSS17, stated by Tamara St. Claire that the very nature of Blockchain “actually incorporate MPI”. She said, “One way to think about it is the fact that not your identification but your data is hashed to the ledger. It’s an address you’re looking for. And there can be multiple addresses. And a patient can hold multiple keys to those addresses in their electronic wallet.”

This means that the Blockchain is able to fit into healthcare interoperability as right player. Besides, all data with clear MPI are prepared data set for deep learning trainings algorithm. Any neural network can easy overtake all MPIs that are securely hashed by Blockchain and place their blocks into

predictable algorithms for population health, optimizing and reducing clinical costs.

Eliminating Middleman. It is already described in the previous chapter, but once again to recapitulate in one sentence: with possibility to eliminate middleman (central data control entity) Blockchain enabled access to data on large scale. This lead also to engage it in a population health. With this the population data are decentralized and accessible directly for deep learning training data sets in the purpose of prediction. This method fulfills one the interoperable gap between interoperability and predictability.

Multiple Source Data Combination. This is one of the basic interoperability requests. Blockchain can overtake a main role as problem solver. It has ability to combine data from various sources of medical devices (or originating devices) and also from mobile and wearable devices sources. Any of the existing EHR or home health device is directly impacted in the data source combination and directly is referred to semantic interoperability.

If the data fit into semantic interoperability they are also easy conversable into machine learning data record set and no need additional adjustments for any predictability methodology.

Blockchain-based technologies will become the foundation for digital innovation that can reach millions of lives. A unique combination of artificial intelligence, smart contracts and the Blockchain will become the nervous system of our society, helping us live longer and healthier lives.

Blockchain has an ability to fill the interoperability gap but still not fulfill it. Hospitals need more infrastructure improvement all over the world so they are technologically based ready and also more healthcare personal resources. Only with that they were be ready to communicate with same language – to be operable.

The aim of predictability is a story mostly hangs around behavioral model, lack of implementation by healthcare innovation leadership and many healthcare utilization patterns, risk adjustments and complexity of healthcare systems. The machine learning with its subset deep learning is on the right way to put predictability in the course of healthcare data interoperability.

Basic efforts and most of the energy in implementation of these technologies will be on the theme of Protected Health Information (PHI) or Personally Identifiable Information (PII). Satisfy a sufficient amount of architectural standards and support systems, this will lead to stability and reliable usability of EHRs.

Pioneering in those two new technologies will help in better understanding and creating new Rolle inside the management of the digital healthcare.

Finding a holy grail to fill the gap is very hard but it is certain in the near future but with noting that the basic postulate the implementing new technologies is improving the conditions of human life in its entirety.

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APPENDIX

Blockchain in Healthcare – Interoperability Flow

