MODERNIZING AND IMPROVING HEALTHCARE WITH BLOCKCHAIN

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ABSTRACT

The Italian healthcare system ranks among the best in the world, however, it struggles to manage waiting times and costs in an efficient way. The average waiting time for a surgery in a public hospital is 57 days and long waiting lists are of course correlated with a reduction in the quality of health of the Italian patients. High costs are mainly due to long waiting lists and to bureaucratic barriers.

In this paper we describe how the application of the BlockChain can improve the overall efficiency.

Contents

1 Introduction

Any industry whose functioning requires different parties to have access to a common set of data can be made more efficient by means of BlockChains. This happens because BlockChains not only facilitate data sharing but they also allow for scalability and efficient ownership chain tracking.

There has been much interest in how BlockChains could improve the healthcare system and what has been found out so far is that the latter may easily benefit from a digitalisation of patients' data, making these an additional source of profits (digital assets).

The major features of BlockChains rendering them perfectly suited to the healthcare industry can be identified in:

- **consistency** with regards to common data shared among different parties;
- **trackability** of the historical evolution of the relevant chain with no chance of unauthorized editing;
- **ownership** meaning that data owners can clearly control who have access to their data, differently from those who sell them and do not know in what hands they go afterwards;
- **decentralisation** avoiding concentration of data in one single and hardly accessible place;
- **transparency** when it comes to BlockChains' rules, which are well-known by the involved parties lamenting no trouble consulting data shared.

All these advantages justify the adoption of BlockChains in the world of healthcare.

2 The bureaucratic problems in healthcare industry

As the development of new technologies and the and application of new facilities, continuous improvements have been made in healthcare industries in recent years. However, there are still several nonnegligible bureaucratic and systematic problems in this industry.

1. **Relatively high medical error rate.** The data of World Health Organization, in most of the European Union Member states, consistently show that medical errors and health-care related adverse events occur in 8% to 12% of hospitalizations.[1] The relatively high medical error rate comes from various reasons, but some of them is man-induced. According to the Agency for Healthcare Research and Quality, there are eight common root causes of medical errors which include, communication problems, inadequate information flow, human problems, and patient-related issues, etc. [2] Since the electrical medical records have not applied widely, and the paper medical records are easily lost or forgot to take, generally the doctors still give their treatment advices based on the descriptions of the patients and the testing results. However, Sometimes the descriptions of the patients may be inaccurate or the patients have some reasons to hide their medical histories, and the testing results also may not exactly reflect the real situation of the patients. Moreover, a lot of processes in healthcare industry are made by people, it also increases the possibility of medical errors. Therefore, to improve the medical results and reduce the medical errors are one of the very important threats of healthcare industry.
2. **Data privacy of the patients.** In early May, an 8-K filing with the Securities and Exchange Commission revealed billing services vendor American Medical Collection Agency was

hacked for eight months between August 1, 2018 and March 30, 2019. Up to 12 million people were affected from the hacking. [3] No matter physical medicals record or electrical medical records, the patients' information and privacies may be possible to be hacked or accessible to others. Even if the data center has a very high security level to anti-hacking, there is as well possibilities for data leakage. Insiders stealing and selling data to commercial firms are not new to happen. Therefore, how to keep the data privacy of the patients is also of great significance for the healthcare industry.

3. **The transparency of healthcare industry is low.** According to the research of some scholars in Pakistan, 21% of doctors choose not disclose the medical errors made by themselves. [4] These scholars carried out the research in 130 pediatric medicine residents. Maybe the 21% of doctors suppose their mistakes will not be recorded or discovered, however, it really shows how the low transparency in healthcare industry will influence. Transparency in healthcare matters, but so far has failed to live up to its promise of transforming quality and cost. Too often progress has been symbolic and has given rise to bitter disputes between politicians and resistant provider and professional groups. Even countries that have led the field are now facing difficult questions about what value is really created for all their effort. Awash with data, some systems are finding it more difficult than ever to work out what is going but used strategically, this study suggests there is considerable potential waiting to be unlocked from health system transparency.
4. **The long waiting time in public healthcare.** There are two unchangeable geographic trends worldwide, one is the rise of total population, another is the aging population. Waiting times arise as the result of the demand and supply imbalance. However, the medical resources, especially quality resources in public sector, are severe limited. Fifteen of the 23 OECD countries included in a study monitor and publish national waiting time statistics. [5] According to the research of Nigerian scholars, the average waiting time before seen by a doctor was 1hr 26 minutes (SD45.51minutes), [6] in Nigeria. Therefore, long waiting times for health care services is an important health policy issue.

3 Our Implementation of the BlockChain

In order to develop this blockchain aimed to reinvent and simplify the bureaucracy that today slows down the entire world of health care, we developed a sort of software from scratch. First, we built two different but complementary versions of our technology, then we highlighted what were the pros and the cons of the two versions and came up with a final implementation by combining the strengths of them and getting rid of the weaknesses.

3.1 Alpha Version: An Interaction among Multiple BlockChains

The first idea we had was to provide each patient, each doctor, and each disease with their own BlockChain. Every patient would have had his or her medical history stored in his or her private BlockChain. Each time a certain patient undergoes a new medical event (which could be a new disease, a medical prescription, a surgery, etc.), a new block in the BlockChain of the patient is mined. This block contains all the data related to the new event that the patient has faced, namely, what kind of event it was, when it happened, who is the doctor who certified this event, and so on.

Contextually, since the doctors and the medical events have their own BlockChain too, also the block containing the data about the patient is added to the BlockChains of the medical event and of the doctor. This way, by looking at the three distinct BlockChains, it is possible to keep track of how many people have contracted that disease, how many patients that doctor has visited and what other medical events the patient has undergone in the past. The most important thing that this technology allows to obtain is the prevention of potential human error and wrong medical prescriptions. In fact, before mining a new block, our technology checks that this new block is compatible with the past events of the BlockChain. If, for instance, the doctor wants to prescribe a drug which is not compatible with a disease that the patient has had in the past, the program will throw an error and will not allow the prescription.

In this setting, the *doctors* are the *miners*, but the *owners* of the BlockChains are the *patients*. The patient has access to the BlockChain containing his or her medical history at any time, but they need to give temporary permission to a doctors if they want to mine a new block. The patient can let a doctor access his or her BlockChain thanks to a system of private and public temporary keys that is well explained in the notebook Simulation.ipynb.

3.1.1 Shortcomings

Although this creation could have a very good impact on the world of health care and could speed up the bureaucracy, there are some weaknesses that could break the whole system and jeopardize the privacy of the patients. First of all, the BlockChain is not decentralized. Everything is stored in this sort of shared database with no decentralization. If the BlockChain gets corrupted, all the data is lost forever.

Moreover, and most important thing, all the different BlockChains are *not* encrypted. It is true that the doctor can only access the BlockChain of a patient if he or she is granted the permission, however, it is also true that, if a hacker manages to somehow access the medical data of a person, this data is free-to-air, meaning that the hacker can read it and share it with whomever he or she wants.

The second "release" of our software tries to address and patch some of these problems.

3.2 Beta Version: Standard Blockchian implementation

In the second version of the blockchain, we decided to develop a standard blockchain. In this framework the miners build the blocks of the chain and get a fee for each transaction they mine. To ensure the right transactions are mined, the blockchain uses 2 ways: a proof of work the miners need to solve and a check of the doctors authorization to ensure only real doctors perform transactions. To do that we used 4 different types of agent performing all the tasks required by the blockchain. Therefore, the agents playing a role in the blockchain are the following: the *Minister of Health*, the *doctors*, the *patients* and the *miners*. Every potential user of this blockchian should decide which role to play. In the simulation we did in the notebook we can think of these agents as types of accounts the user can open when they enter the blockchain.

It must be noticed, then, that anybody can open a doctor account, but only those with a valid authorization issued by the *Minister* can make transactions. At the same time no requirements are requested to be miners or *patients*, while the *Minister of Health* is a unique agent not accessible to users and ideally changes for every country in which we want to scale our blockchain.

This blockchain as the previous one had the feature of checking incompatibilities between illnesses and drugs every time a new prescription was made by the doctor. In addition to that, this implementation also checked the doctors had the right writing permissions to do operations.

3.2.1 Shortcomings

The real problem of this implementation was the data privacy. There was no actual mechanism assessing who could read what and this was a big potential problem for the customer's privacy, since health data are considered to be very sensible data.

While in the alpha version we had the possibility to prevent the doctor from accessing the history of the patient in the future, in this version we did not have anything like that.

3.3 The Final Version

Although our two implementations may seem to differ greatly from each other, with no room for convergence, they are actually complementary. As we mentioned, the two separate versions have some weaknesses; however, a combination of these two versions can eliminate the deficiencies and only keep the positive aspects of the technology that we have implemented. Therefore, this is what we did: we combined our work in order to come up with a powerful, final, unique implementation.

In the final blockchain implementation, there exist 4 classes corresponding to the 4 different actors of the blockchain: *Minister*, *Doctor*, *Patient* and *Miner*. Every class has peculiarities for the different agents and every instantiation of a class can be thought as of user account by which the agent can do the allowed operations related to the class from which it instantiates. For instance, if we instantiate the class Patient in the following way: patient1 = Patient('Mr. Black'), then the patient1 memory address in the local machine will be the address used by the blockchain to do transactions with that particular patient. This allowed us to think to every patient (patient1, patient2 and so on) as real user account from which the patients do operations. The same applies to the other classes.

The blockchain has 3 types of transactions: *diagnosis*, *prescription* and *authorization*. Here an example for each of them. In the first case the doctor makes a diagnosis, and when the block is mined the illness1 is appended to the history of illnesses of that particular patient. In the second case, instead, we have a prescription and in the third case the authorization. In this last case, after the block is mined, the authorization is inserted into the variable authorization of that particular doctor.

1. **type**: 'diagnosis'
   sender: $< unique\_blockchain.blockchain.Doctorobjectat0x0000026A76FAAD30 >$
   recipient: $< unique\_blockchain.blockchain.Patientobjectat0x0000026A76FD5438 >$
   illness: illness1
   fee: 0.2
2. **type**: 'prescription'
   sender: $< unique\_blockchain.blockchain.Doctorobjectat0x0000026A76FAAD30 >$
   recipient: $< unique\_blockchain.blockchain.Patientobjectat0x0000026A76FD5438 >$
   prescription: medicine3
   fee: 0.2
3. **type**: 'authorization'

sender: $< unique\_blockchain.blockchain.Ministerobjectat0x0000026A5FFB7320 >$
recipient: $< unique\_blockchain.blockchain.Doctorobjectat0x0000026A76FAAD30 >$
authorization: $b"ab/bxnon/34/xn/hdnpn68259\jmath$
fee: 0.2

After mining of the block the fee is assigned to the miner who mined the block in the least time. Since it was not possible to run in parallel, we decided to let do the proof of work to each miner, computing the time for each one and giving the fee only to the fastest one. This was done only for simulation purposes.

3.4 Writing Permissions

The idea behind the implementation is that only doctors can do diagnosis or prescriptions to patients, this means that only those who open a doctor account are allowed to perform those transactions. If this is the rule, the problem that comes out is that potentially everyone can open a doctor account from which can send diagnoses to patients. For this reason, it was necessary to create an authentication mechanism by which only doctor verified had writing permissions. The class Minister is useful to do that. Every time a doctor is enabled by the Medical association of the country in which he works, the Minister of Health issues an authorization to them in order for them to make transactions. Technically speaking the authorization is based on the digital signature mechanism. In particular, the unique address of the doctor is signed by the Minister using the private key of the Minister and the resulting encryption is the authorization which is then stored in a variable called "authorization" which is specific of the Doctor class. The creation of the authorization is a transaction as well, where the sender is the Minister of Health, the recipient is the doctor and the object is the authorization. Every time a doctor will do a diagnosis or a prescription, the miner, before mining the block, will try to decrypt the authorization of the doctor using the public key of the Minister of Health. If this goes on, then the authorization is valid, otherwise either the authorization is fake or that doctor still does not have an authorization.

3.5 Checking incompatibilities

The other improvement that the blockchain brings is the possibility to check automatically to incompatibilities among illnesses had by the patient and potential side effects of drugs given by the doctor. In particular, after the check of the doctor's authorization, the miner checks also that, in case of prescription, the patient did not have any illness incompatible with the drug given. To do that, the instantiation of the Minister of Health has a variable called incompatibilities, storing. for each drug, the illnesses which can cause side effects. The miner checks that in an automatized way, without accessing directly the data of the patient. In this way, the Minister is the only agent having all the incompatibilities and new ones can be added only by the Minister.

3.6 Reading Permissions

Since Doctors need to look at the illness history of each patient, they need to have an access to them, but at the same time this has to be done just for a single time, preventing the doctor from having access to the complete history of the patient also in the feature. For this reason, we implemented a temporary key mechanism and the idea is the following: every patient has a private and related public key. If the doctor wants to access the history of the patient, he needs the private key of the patient. The blockchain gets the private key and extrapolate a public key from that, then it retrieves the real public key from the variable of that patient in an automatized way and finally compare the real public key and the one extrapolated by the private passed by the doctor. Once the doctor has access to the history of the patient the private and the public keys of the patient are refreshed. Therefore, if the Doctor tries to access again with the previous private key, the system will throw an error because the real private and so, the real public key has changed.

You can check our final simulation which will guide you step by step in the usage of our final blockchain at the following link: Final blockchain simulation.ipynb

4 Concluding remarks

To sum up, We have made improvements based on the above four problems. First,we try to build BlockChain for four different roles: Minister, Doctor, Patient and Miner.The BlockChain has three types of transactions: diagnosis, prescription and authorization.Writing Permissions ensures that the physician can become Miner and that the patient grants a temporary license to the physician to ensure patient privacy. Second,reducing medical errors by checking for incompatibilitiesthe BlockChain brings the possibility to check automatically to incompatibilities among illnesses had by the patient and potential side effects of drugs given by the doctor,Once the medication is wrong, it raises an error. Third, every doctor's diagnosis of every patient will be recorded and cannot be tampered with, increasing the transparency of the medical profession and making mistakes that cannot be denied. Fourth,while many other factors contribute to long wait times, BlockChain does solve one of them. Doctors do not need to read the description of patients, but only need to read the BlockChain of patients to know the history of all the diseases of patients, which can increase the efficiency of diagnosis, thus reducing the time of diagnosis, so as to reduce the waiting time of patients.

However, we have only improved the technical problems, and more factors, such as human factors, need to be taken into account if the inefficiency is to be solved in practice. Whether the four roles are able to fulfill their respective responsibilities independently, whether the doctor is in collusion with the Minister, and whether the drug information can be recorded accurately and in detail, all these external uncontrollable factors will affect the overall efficiency.

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