Blockchain-Powered Parallel Healthcare Systems Based on the ACP Approach

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***Abstract*— To improve the accuracy of diagnosis and the effectiveness of treatment, a framework of parallel healthcare systems (PHSs) based on the artificial systems + computational experiments + parallel execution (ACP) approach is proposed in this paper. PHS uses artificial healthcare systems to model and represent patients' conditions, diagnosis, and treatment process, then applies computational experiments to analyze and evaluate various therapeutic regimens, and implements parallel execution for decision-making support and real-time optimization in both actual and artificial healthcare processes. In addition, we combine the emerging blockchain technology with PHS, via constructing a consortium blockchain linking patients, hospitals, health bureaus, and healthcare communities for comprehensive healthcare data sharing, medical records review, and care auditability. Finally, a prototype named parallel gout diagnosis and treatment system is built and deployed to verify and demonstrate the effectiveness and efficiency of the blockchain-powered PHS framework.**

***Index Terms*— Artificial systems + computational experiments + parallel execution (ACP), blockchain, parallel healthcare systems (PHSs), parallel intelligence, smart medicine.**

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I. Introduction

SMART healthcare is originated from the concept of smart earth proposed by IBM in 2009 which refers to the integrated use of Internet of Things (IoTs), artificial intelligence, cloud computing, and big data to build an interactive platform for sharing medical information and enable interactions among patients, medical staffs/institutions, and medical equipment [1].

Many researchers have tried to apply artificial intelligence into the field of healthcare to assist doctors in the diagnosis and treatment of diseases. For example, medical imaging diagnostic systems such as DeepMind[1] and Enlitic[2] utilize computer vision for disease diagnosis. Besides, some medical decision-making systems based on cognitive computing such as Watson [2] use data mining and natural language processing to search treatment solutions in a large number of unstructured literatures and patient records such as the patients' medical history, symptoms, and laboratory tests to provide decision supports for doctors [3].

Although smart healthcare systems have made impressive progress in recent years, situations in practical applications are still far from ideal. On the one hand, despite most doctors (especially, expert doctors) have a good knowledge of their own fields, more and more diseases require cross-border medical knowledge of experts from different backgrounds, thus it becomes necessary to have them work together using technological means. On the other hand, due to the regional and individual differentiations among patients, the demands for precise medical care, personalized diagnosis, and treatment are increasing, which makes the accurate patient picturing ever more important than before.

To this end, we propose the framework of parallel healthcare systems (PHSs) based on the artificial systems + computational experiments + parallel execution (ACP) approach. First, an artificial healthcare system (AHS) is constructed, to depict and model the patients' and the doctors' static and dynamic features, which is called the "descriptive intelligence." Second, by adding different types of disease scenarios in AHS,

[1] DeepMind. https://deepmind.com/
[2] Enlitic. https://www.enlitic.com/

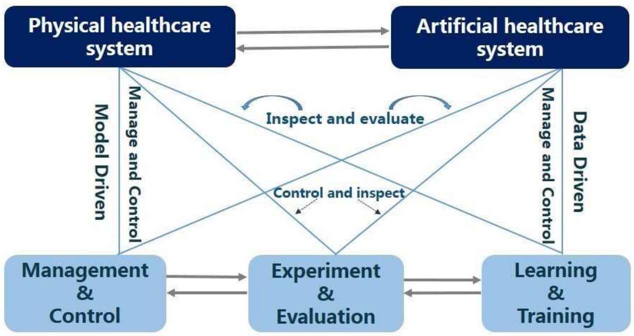

Fig. 1. Framework of PHS.

computational experiments are used to test and evaluate the applicability of various therapeutic regimens, thus to achieve the "predictive intelligence." Third, the final regimen is chosen from a recommended list by an expert and parallel executed in both the AHS and the actual healthcare system, to realize "prescriptive intelligence."

In addition, the emerging blockchain technology is applied into the construction of PHS. More especially, a consortium blockchain that contains patients, hospitals, health bureau, healthcare communities, and medical researchers is deployed, and blockchain-powered smart contracts are used to enable electronic health records (EHRs) sharing, record review, and care auditability.

The rest of this paper is organized as follows. Section II outlines the framework of PHS. Section III reviews the typical applications of the blockchain technology in the field of healthcare. Section IV presents a prototype parallel gout diagnosis and treatment system (PGDTS) to verify and demonstrate the effectiveness and efficiency of the blockchain-powered PHS framework, which has been successfully deployed in the affiliated hospital of Qingdao University for two years. Section V analyzes the future trends of blockchain-powered smart healthcare systems. Section VI concludes this paper.

II. Framework of Parallel Healthcare System

Parallel healthcare is the application of a parallel theory implemented in the medical field. The parallel theory comes from the ACP approach [4], which contains artificial systems, computational experiments, and parallel execution. Especially, the artificial system is built for modeling and representation, computational experiments are utilized for analysis and evaluation, and parallel executions are conducted for the control and management of complex systems [5].

As shown in Fig. 1, the parallel healthcare consists of a physical healthcare system and AHS.

The physical healthcare system is the medical scene in reality, mainly represents doctors and patients. The physical healthcare process consists of making disease diagnosis, determining treatment plan, and carrying out treatment plan. In particular, the AHS is the core of PHS, built according to the physical healthcare system, is paralleled to the physical healthcare system. Accordingly, there will be artificial doctors and artificial patients. The AHS will participate in each step what the physical healthcare system performs and can transfer the incomputable disease diagnosis and treatment processes into computable one.

Once the AHS is built, the computational experiments will be utilized for a medical process for making disease diagnosis and determining treatment plan. Initially, the AHS will make diagnoses based on patient's symptoms according to medical knowledge from medical publications and doctors' clinical experiments. Later, the artificial system will evaluate all kinds of the therapeutic regimen in digging out the best solution against the patient medical condition. Eventually, the artificial system will monitor the patients for the treatment effectiveness through virtual–real interaction between the AHS and the physical healthcare system together with treatment results feedback. If the treatment effectiveness is not in line with what the system expected, it will adjust the treatment plan timely and continue to monitor. This procedure is named as parallel execution [6], [7].

In the following, we will introduce the three main components of the PHS, namely, the AHS, the computational experiments, and the parallel execution in detail.

A. Artificial Healthcare System

From the perspective of modeling [8], the PHS consists of the physical healthcare system and the software-defined artificial disease diagnosis and treatment system [9]. The physical healthcare system includes real doctors and patients. Correspondingly, the artificial system includes the software-defined doctors and patients (virtual ones). We will describe them separately.

Regarding to real doctor, the artificial doctor is consisted of three different virtual ones, we call them descriptive doctor, predictive doctor, and prescriptive doctor.

1) *Descriptive Doctor:* The descriptive doctor is the integration of the medical knowledge and clinical experiences from real doctors, it can be considered as an intelligent robot possessing adequate skills in making diagnoses and treatment schemes for the patients, and owning to the same characteristics of real doctors [10].
2) *Predictive Doctor:* The predictive doctor is an ideal doctor who possesses perfect medical skills and comprehensive medical knowledge, as it outperforms any single real-world doctor by its advantage in knowledge assembling and experience accumulation from various medical professionals. In our PHS, the predictive doctor is constructed by knowledge graph (a structured semantic knowledge base, in which the knowledge can be used for reasoning and computing). The predictive doctor makes diagnoses and treatment plans for the artificial patient (we will introduce it later), then performs a real-time observation and evaluation of treatment effectiveness through computational experiments.
3) *Prescriptive Doctor:* The prescriptive doctor refers to a set of optimal artificial doctors obtained via experimental verification based on different therapeutic effectivenesses.

The artificial patient is a patient model that is constructed by simulation of the real-world patient, and is consistent with the real patient. The artificial patient is built by recording the biological characteristics, social relations, and environmental characteristics of the real patient. Similar to the artificial doctor, the artificial patient consists of descriptive patient, predictive patient, and prescriptive patient as follows.

1) *Descriptive Patient:* The descriptive patient is a data-driven agent regarding the information of the real-world patient, including his/her basic information such as age, gender, marriage, and occupation, along with health information including his/her medical records, history of allergies, genetic test report, and so on.
2) *Predictive Patient:* The predictive patients are different versions of the patient (based on the one particular real patient from distinct medical perspectives) on whom the artificial doctor can conduct various kinds of diagnoses and treatment experiments, thus can help find the most reasonable diagnosis and effective treatment scheme according to the experimental results [11].
3) *Prescriptive Patient:* The prescriptive patient is the patient receiving the optimal treatment and reaching the expected goal of treatment effectiveness before applying to an optimal scheme treatment to the real patient. Afterward, the prescriptive patient will keep pace with the real patient to monitor the real patient and help the real patient to achieve the goal of the treatment scheme [12].

B. Computational Experiments

The medical computational experiments in PHS are mainly used not only to make the most reasonable disease diagnosis but also to propose and evaluate the potential treatment schemes for a particular patient through knowledge reasoning or other computable way. Generally, the computational experiments include diagnosis computational experiments and treatment computational experiments [13].

The diagnosis computational experiments will be carried out under the principle of an evidence-based medicine, which combine clinical evidence, personal experiences, and the real condition of patients. Our artificial doctor will learn certain diagnosis standards in medical publications for each existing disease, learn the empirical diagnosis knowledge from the large historical cases, and also learn the methods of different diagnoses and evidence-based medicines. To achieve the diagnosis process, the artificial doctor will be created based on the present symptoms, medical examination results, past medical history, family medical history, and other information from the descriptive patient. Later, artificial doctors use the corresponding diagnosis knowledge to infer and compute the probability of related diseases. In many times, a patient may suffer from many diseases, especially for the elderly, and there is a mutual relationship between various diseases. Thus, the artificial doctor will learn from the diseases, find the probable source of the diseases, and give the patient a precise diagnosis. Besides, if the information is insufficient to give a certain diagnosis, the descriptive patient will ask the real patient for more details until reaching a reasonable diagnosis.

The treatment computational experiments will be carried out after the real doctor adopted the diagnosis made by the artificial doctor. The treatment computational experiments are more complicated than the diagnosis process because a standard treatment scheme is not feasible in many cases, especially for a patient suffering from many diseases. In reality, doctors will give a treatment scheme by their experiences, since the treatment scheme from different doctors would be various for the same patient. Therefore, the task of treatment computational experiments is to derive many different treatment schemes according to the diseases the patient suffers as the different doctor will do. Then, the predictive doctor will apply different treatment schemes to various predictive patients that derived from the real patients, and simulate and compute the effectiveness of different treatment schemes. The treatment computational experiments are based on the real doctor's treatment principle, and adhere to the idea of treating different diseases with the same origin and treating multiple diseases with the same treatment, and apply pharmacodynamics and pharmacokinetics to simulate and compute the effectiveness of different treatment schemes [14]. Eventually, the predict doctor will recommend the best treatment scheme for the real doctor as the result of the treatment computational experiments.

With the development of knowledge graph, the knowledge-based reasoning provides an effective way to carry out the computational experiments. The knowledge-based reasoning mainly contains generative reasoning, symbolic logic reasoning, and statistical reasoning. Generative reasoning can realize the rule-based and data-driven knowledge reasoning. The symbolic logic reasoning and statistical reasoning can achieve the knowledge of self-learning [15].

C. Parallel Execution

The parallel execution is the interaction of AHS and the actual healthcare system. The parallel execution mainly consists of two aspects as follows.

The first aspect is the parallel execution between the real doctors and artificial doctors. On the one hand, when artificial doctors conduct the diagnosis computational experiments and make the disease diagnosis, the real doctor will confirm the result through the interaction with the artificial doctor and make the eventual diagnosis. On the other hand, when the artificial doctor choose the best treatment scheme, the real doctor will give his opinion about the result and give the eventual treatment scheme to the real patient. However, when the diagnosis and treatment scheme of the artificial doctor are inconsistent with what real doctors offer, there are probably two reasons, one is that the artificial doctor made a mistake and provide a wrong result, the other is that the doctor made a mistake. For the former, the artificial will learn from this case and become more intelligent. For the later, the artificial doctors will provide reasoning basis thus a misdiagnosis or mistreatment will be avoided next time. At the same time, the real doctor can learn from the case and become more professional.

The second aspect is the parallel execution between the prescriptive patient and real patient [16]. The prescriptive patient will continuously monitor the changes of all the biological indicators of the real patient. Besides, the prescriptive patient will also guide real patients to receive the treatment based

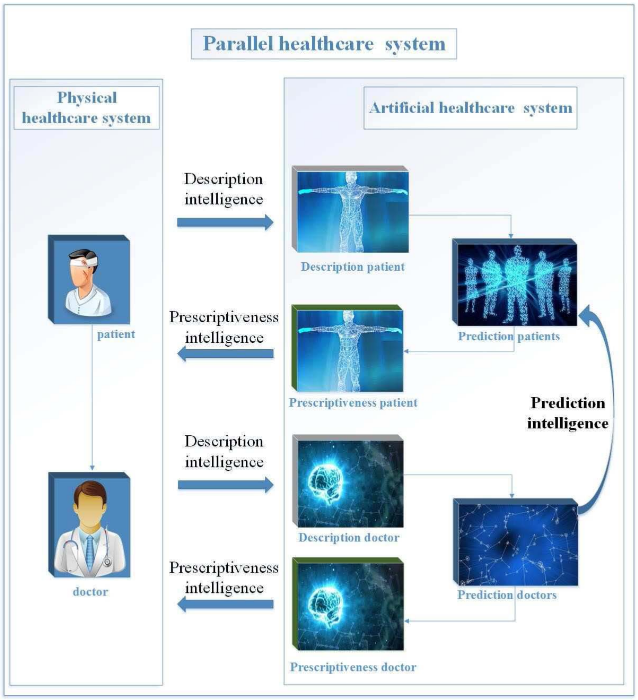

Fig. 2. Parallel healthcare: new paradigm shift.

on the optimal therapeutic regimen calculated previously. The prescriptive patient will provide long-term disease control and chronic disease management in regarding to real-time information feedback. If there is a huge deviation of the therapeutic effect between the real patients and the predictive patients, the prescriptive patients will notify the deviation reasons to the artificial doctor with requesting a recalculation of the treatment scheme and adjust it timely.

In brief, the PHS based on the ACP approach provides a new paradigm to transform a classical medical process into a computable one and provides a precise medical service for both the doctors and patients. Through the interaction with artificial doctors, the parallel medical system would help real doctors to improve their medical skills and to avoid misdiagnosis or mistreatment. Meanwhile, through the interaction with real doctors, the AHS's performance will be improved as well. Last but not least, the parallel system can also provide the personalized guidance for each patient with "all-weather" medical suggestion about their treatment scheme, diet, exercise, rehabilitation, and so on, which can help patients to recover quickly [17], as shown in Fig. 2.

III. Application of Blockchain Technology in Smart Healthcare

In this section, we give a brief overview of the blockchain and smart contracts, then list some typical applications of the blockchain technology in smart healthcare.

A. Overview of Blockchain and Smart Contracts

In recent years, with the popularity of digital cryptocurrencies represented by Bitcoin and Ethereum, the blockchain technology has received an extensive attention. The blockchain is a continuously growing list of records, called blocks, which are linked and secured using cryptography. The blockchain can be regarded as an open, distributed ledger that can record transactions between two parties efficiently and in a verifiable and permanent way [18]. The consensus mechanism ensures a common, unambiguous ordering of transactions and blocks, and guarantees the integrity and consistency of the blockchain across geographically distributed nodes. The development of the blockchain technology has enabled a customizable programming logic to be stored in a decentralized way. This has revived the notion and facilitated the creation of smart contracts. Smart contracts are software programs that self-execute complex instructions on blockchains. The smart contracts permit trusted transactions and agreements to be carried out among disparate, anonymous parties without the need for central authorities, legal systems, or external enforcement mechanisms [19], [20]. The applications of blockchain and smart contracts are springing up, covering financial assets exchange, digital identity certification, distributed file storage, IoTs, and so on.

B. Application of Blockchain-Powered Smart Healthcare

Blockchain has three typical applications in the healthcare field, namely, fast healthcare interoperability resources, user-oriented medical research, and counterfeit drug prevention and detection.

1) *Fast Healthcare Interoperability Resources:* Up until now, the patients do not have control over the access privileges to their EHRs and remain unaware of the tremendous value of these data. With the help of the blockchain technology, healthcare payers and providers can manage medical records and clinical trials data while maintaining regulatory compliance. For example, MedRec [21] is a novel, decentralized health records management system. With it, the patients can build a holistic record of their health data and authorize others for viewership. MeDShare [22] is another blockchain-powered system that provides data provenance, auditing, and control for shared medical data in cloud repositories among healthcare providers, healthcare entities, and medical researchers. Besides, its design employs smart contracts and an access control mechanism to effectively track the behavior of the data.
2) *User-Oriented Medical Research:* Health researchers often require broad and comprehensive data sets in order to advance the understanding of diseases, accelerate biomedical discovery, and design customized individual treatment scheme based on patients' genetics, lifecycle, and external environment. The blockchain can effectively speed up the development process. A framework called ModelChain [23] is proposed to improve the security and robustness of distributed healthcare predictive modeling using the private blockchain; Gems,[3] a blockchain air position indicator provider, announced a partnership with Philips to build an Ethereum blockchain

[3]Gems. https://gems.org/

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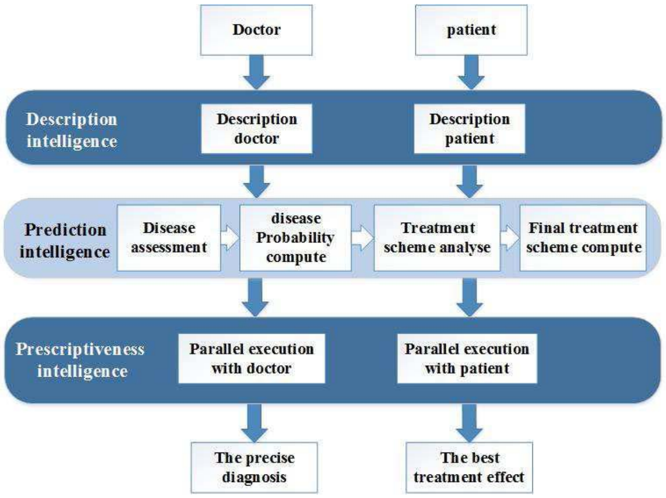

Fig. 3. Parallel gout diagnosis and treatment system.

for use in the development of an enterprise healthcare application.

3) *Counterfeit Drug Prevention and Detection:* Counterfeit drug poses a serious threat to the people's health. The interoperability, data security, and authenticity of the blockchain allow the healthcare and life science industries to indelibly record the medicinal data that will effectively combat counterfeit pharmaceutical property and protect intellectual property. The MediLedger Project[4] designs and implements a process that improves the track-and-trace capabilities for prescription medicine as the blockchain makes it easy to track drugs when they move from the manufacturers to the patients. BlockMedX[5] aims to address the rampant opioid crisis in the U.S., the service is designed to be used by physicians and pharmacies to help increase security and accountability in the prescription drug industry.

IV. Parallel Gout Diagnosis System: Prototype System Implementation

Gout has become the second largest metabolic disease, and the misdiagnosis and substandard treatment of which will cause the patient to suffer more with increasing the severity of the symptom [24]. Thus, it urgently requires precise clinical diagnosis and treatment methods to help the patients overcome gout. In order to verify the effectiveness of the proposed PHS, we constructed a parallel gout diagnosis system, as shown in Fig. 3. The system has been successfully deployed in the affiliated hospital of Qingdao University, Qingdao, China [25].

To apply PHS in the gout diagnosis and treatment, we divide our AHS into three subsystems, which are the hospital clinical system, the gout diagnosis and treatment system, and the patient care system. The hospital clinical system aims to construct the artificial patients according to their medical record and medical examination results. The goal of the gout diagnosis and treatment system is to build the artificial doctor with medical knowledge and make a computational experiment for the gout diagnosis and treatment scheme. Meanwhile, the patient care system is to achieve the parallel execution between the artificial and real patients.

A. Hospital Clinical System

The hospital clinical system is designed for managing artificial patients and collecting information of real gout patients to build and update artificial patients. Once built, the artificial patient will stay in the hospital clinical system permanently. Each time the patient has an update regarding his/her medical record, the artificial patient will sync with this update. The records include medical examinations, doctor's diagnosis details, treatment schemes, and so on. Therefore, it is convenient to show the disease information and the changes of each medical indicator after the patient received the treatment scheme. Besides, the hospital clinical system provides the real doctor parallel execution with the artificial doctor to make the diagnosis and treatment scheme [26]. Real doctors can get the diagnosis result and the treatment scheme from the gout diagnosis and treatment system as reference before the final diagnosis and treatment scheme is made. Therefore, the hospital clinical system realized the "description intelligence" [27].

B. Gout Diagnosis and Treatment System

The gout diagnosis and treatment system is to conduct the computational experiments of the gout diagnosis and treatment scheme. The system builds an artificial doctor based on knowledge graph, which becomes one of the most promised methods to manage and use knowledge in computer. The artificial doctor integrates the real doctors' professional knowledge, clinical experience, reasoning modes, and the actual gout cases with knowledge graph.

1) Diagnosis Computational Experiments: Gout is a metabolic disease mainly caused by the increase in uric acid in the blood and typical symptoms are joint pain and high blood uric acid. Gout can be discerned from rheumatoid arthritis, osteoarthritis, pseudogout, and systemic lupus erythematosus by differential diagnosis. Besides, gout patients often suffer from other diseases, and these diseases affect each other, so it is necessary for the patient to make a thorough diagnosis of all diseases, thus helping the doctor give precise treatment scheme from the perspective of the system. However, it is difficult for a real doctor to be professional in all kinds of diseases, whereas it is easy for an artificial doctor. The reason is that the artificial doctor can quickly and comprehensively master medical diagnosis knowledge via knowledge graph. The gout diagnosis computational experiments [28] were carried out by combining gout knowledge and clinical experiences together. On the one hand, the diagnosis knowledge comes from the knowledge graph, which can learn knowledge from medical publications. Then, we transform the unstructured information into structured knowledge. The diagnosis computational experiments are achieved through knowledge reasoning in the knowledge

[4]MediLedger Project. https://www.mediledger.com/
[5]BlockMedX. https://www.blockmedx.com/

graph. On the other hand, the artificial doctor can learn from the history cases and transform the cases into clinical experiments through deep learning, while real doctors cannot similarly learn clinical experiments from a large number of clinical patients easily. With the advantage of computer in computing speed, storage, and portability, the artificial doctors could have better performance than the real doctors could have.

2) Treatment Computational Experiments: The artificial doctor will apply different kinds of gout therapeutic regimens for a certain patient, then evaluate all possible therapeutic results of computational experiments based on the artificial patients, and predict the best treatment scheme. At present, we adopt the knowledge graph searching and knowledge reasoning technology to achieve it. Another feasible approach is deep learning that we can make the gout knowledge graph as the input of the neural network, and then the neural network will make full use of the prior knowledge existing in the knowledge graph to realize the prediction. The gout diagnosis conducts a large number of computational experiments to predict the disease and evaluate all the possible effectiveness of various treatment scheme options to obtain the optimal gout treatment scheme. Thus, the gout diagnosis and treatment system realized the "prediction intelligence."

C. Patient Care System

The patient care system monitors and assists the patient in implementing the treatment scheme. Moreover, the system will record the patient's medical indicators such as uric acid, blood pressure, creatinine, blood lipid, blood glucose, and other medical indicators to demonstrate the changes before and after receiving the treatment. The expected value of these medical indicators in artificial patients was predicted by computational experiments. Therefore, the artificial patient guides the real patient to receive the treatment to achieve the expected goal and track the medical indicators of the real patient in the patient care system. Once there is a deviation between the real patient and the expected artificial patient, the parallel system will analyze and evaluate the feedback information to determine whether to give proper recovery advice to the doctor and the patient. Consequently, the patient care system conducts the virtual–real interaction between the patient and artificial patient to achieve the "prescriptiveness intelligence" [29].

D. Gout Consortium Blockchain

Now, we are trying to establish a gout consortium blockchain [30] containing patients, hospitals, health bureau, and so on. The health bureau has the highest management and supervision authority. Hospitals can view the patients' medical history under their authorizations and upload the patients' EHRs to the blockchain. Patients can create, update, or query their personal and medical information according to the predefined limits of the authority, as shown in Fig. 4.

The clients, including the patient clients and the doctor clients, are the components used in the gout consortium blockchain to generate transactions. The contents stored in

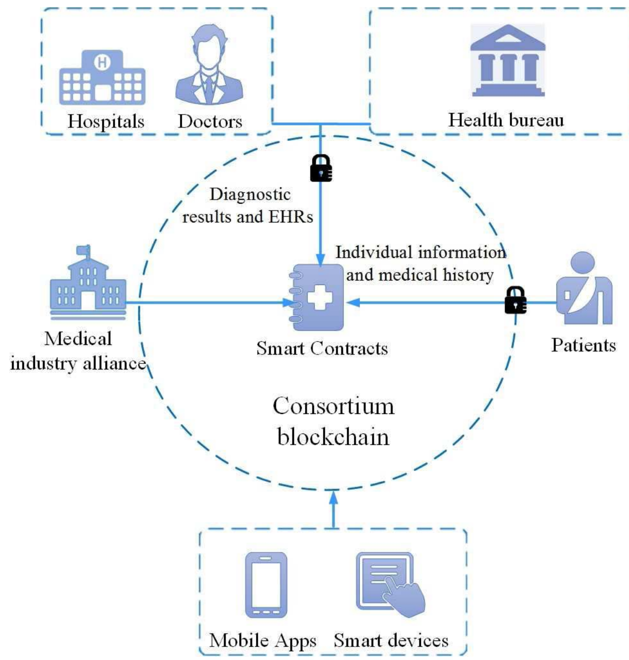

Fig. 4. Consortium healthcare blockchain.

the transactions mainly contain the patients' individual information (name, gender, age, and marriage), doctors' diagnosis information (time, location of the diagnosis, and the consultation results), and medical records information (e.g., medical images, videos, pathological examination results, and so on). To facilitate the storage, we can only store the hash value of these data on the blockchain. Besides, in order to ensure the anonymity while using the medical data efficiently, a controllable anonymity technology can be used [31], [32].

The consortium blockchain adopts delegated proof of stake (DPoS) mechanism to achieve consensus among nodes. DPoS is a fast, efficient, and flexible consensus model leveraging the power of stakeholder approval voting to resolve consensus issues in a fair and democratic way. The nodes in the consortium blockchain elect a certain number of trustees called delegates who take turns to collect transactions in the network and package them into a block. Then, other nodes will verify the validity of the block and appended it to the existing blockchain. The blockchain-powered smart contracts will enable the comprehensive data sharing and record review. The health bureau will serve as the audit nodes to ensure the integrity of the whole system. Besides, an analytics layer will be added for disease surveillance and epidemiological monitoring [33].

We believe that the consortium blockchain will bring the following advantages to the existing parallel gout diagnosis system.

1) *Data Integrity:* By design, the blockchain has characteristics of decentralization, tamper resistant, and auditability. With blockchain in place, the patients can take back control of their personal medical records, and any change of the records will be retroactively examined to see precisely how it has changed over time and who made these changes.

2) *Interoperability:* The blockchain-powered health information system could unlock the true value of the interoperability. Up until now, the patients' health information are inherently fragmented and dispersed across multiple providers and organizations, such as hospitals, community clinics, general practitioners, specialists, diagnostic clinics, and so on. The blockchain enables patient information to be shared across multiple providers with no risk of security or privacy breaches. What's more, with the blockchain network being shared with authorized providers in a secure and standardized way, the costs and burden associated with data reconciliation will be eliminated.
3) *Facilitating Medical Research:* Utilization of the blockchain technology will engage millions of patients, healthcare entities, medical researchers, healthcare providers to share vast amounts of data related to every aspect of the patients' life. On the one hand, patients could actually profit from it as they can provide their health and demographic data to medical researchers in exchange for some tokens; on the other hand, it gives timely access to the medical data that healthcare professionals can use to make crucial diagnosis and deliver appropriate treatments. This could lead to precision medicine and advancement of medical research to pave the way for improved health and timely prevention of diseases.

V. Future Trends of Blockchain-Powered Parallel Healthcare System

A. Bit Patient

In the future, we plan to build bit patient for each artificial patient. Bit patient is the digitization of a particular patient's vital signs (such as pulse, respiration, body temperature, blood pressure, and glucose concentration). Wearable devices, smart hardware, and intelligent sensors can be used to upload those medical data to the blockchain. The inherent durability and attack resistance of the blockchain ensure the data security and traceability. When an abnormality occurs in a bit patient's vital signs, the bit patient will send out an alarm and then transfer the data to the artificial doctor. Then, the artificial doctor will analyze the abnormal data and assist the human doctor in diagnosis and treatment.

B. Distributed Ledger of Medical Data

As mentioned earlier, the medical data stored in various formats and scattered across incompatible systems, leaving patients with no consolidated view of their true medical history. Our PHS aims to break such "information isolated islands" because the blockchain will remove the silos by safely integrating the medical data dispersed in different institutions. Patients, doctors, and medical research institutions can all benefit from it. For patients, they can enjoy more professional and customized medical services while saving time and costs. Besides, they can set different read–write access permission for their medical records based on their needs, so they can fully own and control their medical information; for doctors, as the blockchain allows the medical data to be transferred within the healthcare system in a safe and shared manner, their work efficiency will be greatly improved (because the nodes on the blockchain network are updated synchronously, the patient's treatment data in hospital A can automatically synchronizes to hospital B, thus doctor in hospital B can follow the patient's previous treatment data seamlessly); for medical research institutions, they can use the data to develop new medical applications under the authorization of the patients.

C. Decentralized Parallel Healthcare Organizations

With the rise of blockchain 2.0 represented by Ethereum, the decentralized autonomous organizations (DAOs) (sometimes labeled as decentralized autonomous corporations) are emerging. DAO refers to a form of organization that operates autonomously through a series of open and fair rules without external intervention. It runs through rules encoded as computer programs (smart contracts) and its transaction records and administration rules are all maintained on the blockchain. To some extent, DAOs are like software agents, when the programs are set up, they will operate autonomously according to the established rules.

We think that the future organizational form of the proposed PHSs is DAOs, which we called Dencentralized Parallel Healthcare Organizations (DPHOs). Patients, hospitals, health bureaus, health care communities, medical researchers, and insurance companies will all participate in the "co-ownership, co-construction, and co-sharing" of the entire medical ecosystem as a member of DPHOs (as mentioned in Section IV, it could be in the form of consortium blockchain). The decentralized nature and the economic incentive of the blockchain will promote the mutual trust sharing, thus establishing a transparent and credible relationship among the related participants. In this process, the decentralized applications and smart contracts will play an important role. For example, in the field of medical insurance, once the predefined conditions of the smart contracts are triggered, the insurance claims can be settled instantly.

Furthermore, Yuan and Wang [34] proposed the conceptual framework, fundamental theory, and research methodology of parallel blockchain. We believe that the ACP approach can be naturally combined with the blockchain to realize smart contracts-driven PHSs in the near future. This is because the parallel blockchain enables a variety of "WHAT-IF"-typed virtual experimental design, experimental scenarios deduction, and experimental results evaluation, and through the virtual–real interactions and parallel evolution between the physical and AHSs, the optimal treatment decision for a specific medical scenario could be obtained.

VI. Conclusion

In this paper, we present the framework of blockchain-powered PHS based on the ACP approach. The PHSs use an artificial system modeling to simulate and represent the actual healthcare scenarios; then, the training and evaluation of various disease diagnosis and treatment schemes are performed through computational experiments; through parallel execution between the actual and AHSs, the accurate forecasting and guidance of the disease diagnoses and treatments are realized. Next, we review the application of the emerging blockchain technology in the healthcare field and present a preliminary prototype system of the proposed parallel healthcare framework called PGDTS which has been successfully deployed in China. We also propose to build a consortium blockchain that contains patients, hospitals, health bureau, and so on with the purpose of enabling the PHS more integrity, scalability, and security. In the future, we will further improve the blockchain-powered PHS and make it available for more disease treatments scenarios.

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