Enhancing Healthcare Data Integrity and Interoperability with Blockchain and Smart Contracts

Mrs.R.Arulmozhi, Mr.S. Karthiraja, Mr. M. Kirubhakaran, Mr. A.Logesh Krishnan,
Mr. S.Mohammed Suhail Manas,Mr. S.Abdul Thowfeeq,
Al-Ameen Engineering College,Erode

Abstract

Blockchain technology, a decentralized and distributed ledger system, has evolved beyond financial applications to revolutionize healthcare services. In an era where data mining plays a crucial role in uncovering valuable insights from vast datasets, healthcare systems require robust solutions to maintain patient data integrity and security. Traditional Electronic Health Records (EHRs) have faced challenges due to compliance constraints, limiting their adaptability and efficiency. This study explores the potential of blockchain-based smart contracts, particularly within the Cardano network, to enhance the security, ownership, and interoperability of health records. By leveraging smart contracts, healthcare providers can create intelligent approximations of existing medical records while ensuring transparency, data integrity, and patient control over personal health information. The decentralized nature of blockchain eliminates intermediaries, reducing costs and improving system reliability. Additionally, blockchain offers a scalable and transparent framework for managing digital health records, leading to better patient care and more efficient treatment strategies tailored to individual needs. This paper discusses the advantages of blockchain-enabled healthcare systems and highlights how smart contracts facilitate secure, interoperable, and cost-effective management of medical data.

Keywords: Blockchain, Data mining, Carando Smart Contract, health records, interoperability.

1. Introduction:

Deep learning has exploded in popularity in recent years due to its ability to make well-informed conclusions. Many of today's deep learning systems rely on centralized servers and lack operational visibility, accountability, dependability, security, and trustworthy data origination features.[1-5] Furthermore, using centralized data to train deep learning models is prone to the single point of failure problem. The significance of combining blockchain tech with machine learning is examined in this study.

Deep learning's potential has been seen in practically every healthcare sector. In the healthcare industry, for example, clinicians employ deep learning models to accurately identify a patient's ailment based on their symptoms.[6-10] Deep learning models were used to anticipate the disease scatter rate in a specific area during the latest pandemic induced by the propagation of coronavirus disease (COVID-19) and help officials in controlling the pandemic utilizing the predicted outcome.

Furthermore, utilizing a dataset of CT and X-ray pictures, novel learning techniques have aided health professionals in identifying COVID-19 cases. [11] Apart from healthcare apps, security officers at airports have used deep learning to detect and validate restricted goods in travelers' luggage or to protect software from flaws.[12-17] Supervised learning algorithms can help authorities recognize any physical threats in real-time by using biometric scanners and face identification features. The data quality utilized during the model training stage determines the efficacy and efficiency of a machine learning system.[18] Any change to the data used for deep learning procedures can cause the training model to be corrupted. Blockchain is a decentralized system capable of handling the integrity of data, privacy, and confidentiality with ease.[19] The combination of blockchain and deep learning may provide many advantages, including robotic and verified decision making, efficient data market administration, data security, improved model formulation for forecasting, model sharing, and increased resilience of deep learning-based systems.[20-23] Figure 1 shows a few data mining algorithms and benefits, as well as an explanation of each user's role. Deep learning has the capability for image processing, sensor data analysis, voice identification, text forecasting, and OCR-based systems in terms of efficient information processing.[24] To train the models, conventional deep learning systems used cloud-based systems to manage and store massive amounts of data. By using clusters of CPUs and GPUs for efficiently executing compute-intensive activities, cloud computing helps accelerate the learning process of artificial intelligence[25]. Wearable devices, for example, can gather and transmit significant amounts of healthcare data to cloud servers via a trusted edge server in telehealth and telemedicine-based applications.[26] In the second phase, this healthcare data is processed using learning models on resource-rich cloud storage to detect patterns in the information. Many conventional methods, on the other hand, are unable to completely realize their potential due to the limitations imposed by existing systems' centralized design. Furthermore, storage arrays and processing that are centralized increases the risk of a single point of failure. Because data is so important in a deep learning system, it needs to be well-protected against both internal and external attacks.[27]

The distinguishing characteristics of blockchain contribute to the resilience of deep learning methods by shielding data from a variety of adversarial attacks. By definition, blockchain is a tamper-resistant and tamper-proof system that aids in the monitoring of data to verify that it has not been changed since its inception. Data preservation, openness, privacy, traceability, authenticity, and operational transparency are among the major benefits of new blockchain technologies, which are envisioned by the decentralized and peer-to-peer (P2P) design of blockchain. Self-executing smart contracts can be used to automate healthcare activities on the blockchain system, removing the need for service providers to carry out the services. The smart contract permits the creation of a low-cost, quick, and dependable deep learning system.[28] Blockchain technology allows for the authenticity of deep learning methods to be established, resulting in trusted AI systems.[29] It captures the many phases of the model during its development, modification, or use and records the development of deep learning techniques as they advance. More specifically, it uses the blockchain's record of irreversible activities to help identify the proprietor of deep learning models, databases, data sources, users, the base form, and procedures involved in model building. Attacks against AI models, like information, prototype, and algorithm poisoning, are impossible due to blockchain characteristics like consensus method, data integrity, and cryptography functions. [30]

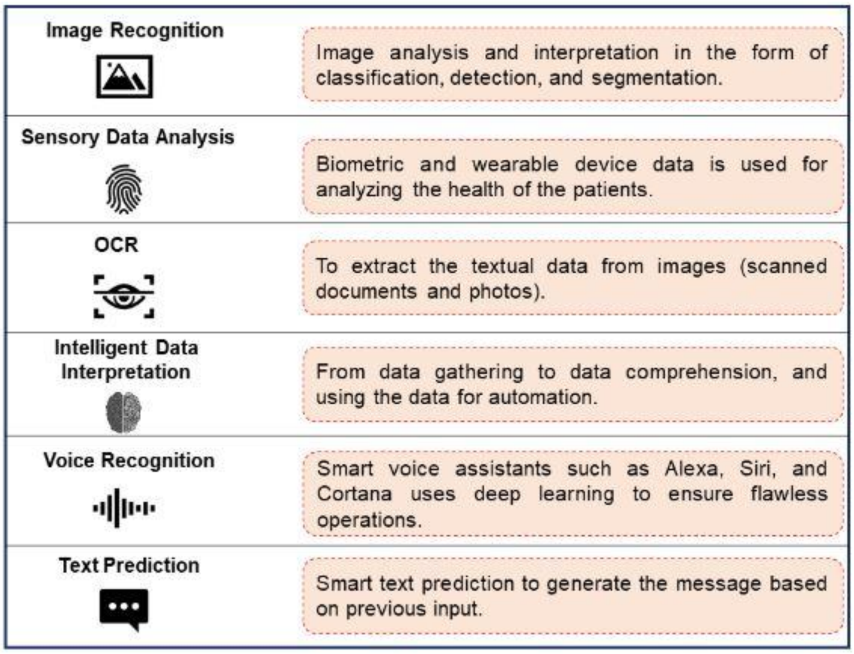

Fig. 1: Deep learning algorithms have many advantages in the healthcare field.

2. Background

This section briefly reviews the key characteristics of blockchain and deep learning, as well as the advantages of combining them in terms of database security, automated decision-making, and increased resilience in the healthcare system.

2.1. Blockchain Technology

Hackers will find it incredibly difficult to edit, manipulate, or destroy anything stored on the blockchain. It is a decentralized system that stores and processes transactions and data using a peer-to-peer (P2P) architecture. It is made up of a large number of nodes that validate and store transactions in the form of blocks. Smart contracts, which are digital programs that operate only when certain conditions are met, are another essential component of blockchain technology. Smart contracts are designed to help organizations reduce risk and costs. Data integrity, smart contracts, consensus protocol, and decentralization are all significant qualities and aspects of blockchain technology that help improve corporate effectiveness. Patients' electronic health records (EHR) and personal health records (PHR) can be protected with blockchain technology. This can help patients have control and management over their data, and that it is shared with other users by the patient's authorization management policy. Self-executing smart contracts are used to execute consent administration procedures.[31] However, if adequate solutions are not adopted to manage large-scale healthcare data, blockchain is a costly technology. To fully utilize blockchain in various healthcare systems, markers and connectors can be extremely useful in reducing data size. Furthermore, decentralized storage systems can safely store massive amounts of data while avoiding single-point-of-failure issues. Cassandra, InterPlanetary File System (IPFS), Storj, SWARM, Skeps, and OrbitDB are some of the most extensively utilized decentralized storage devices in the healthcare sector.

2.2. Deep Learning

Deep learning is a subset of artificial intelligence and machine learning. A model analyzes the hidden space structure of the most fundamental kind of data, such as visuals, text, and audio data, in current deep learning systems. The link between deep learning, AI, and machine learning is depicted in Figure 2. Deep learning enables the hardware to perform many tasks with human-like precision, or even superior to humans in some circumstances. Image classification, object recognition, disease prediction, and voice management are just a few examples of deep learning's wide range of applications.[32]

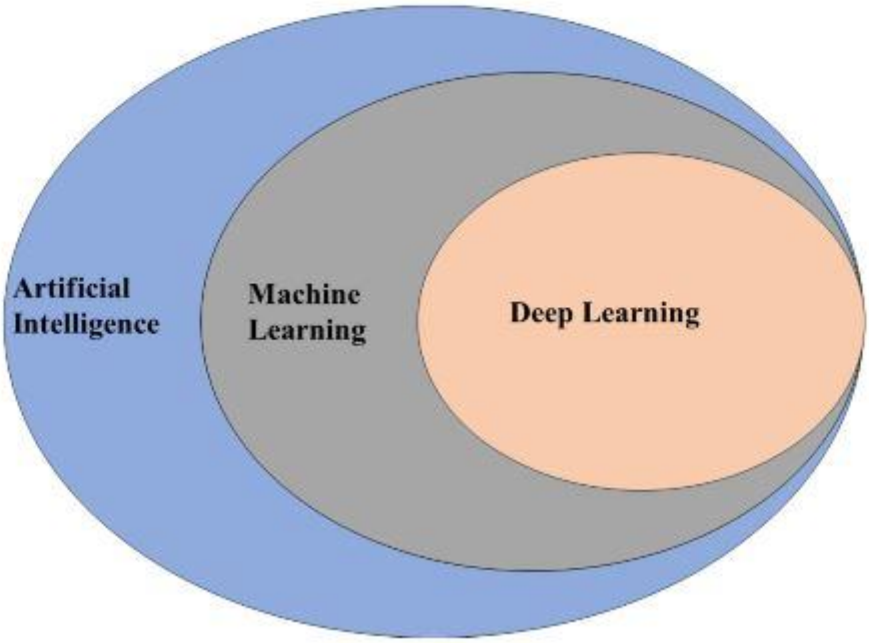

Figure 2 Link between AI, Machine learning, and deep learning

ML algorithms can learn multinational data sequences with the use of data representation strategies.[33] As a result, data integrity is crucial in machine learning algorithms that use time-series information to make the right conclusions. More specifically, regardless of how sophisticated the method is, if the data has poor specifications, the model will not work well on these data. As a result, feature engineering is regarded because it can aid data restoration by utilizing sets of features extracted from original data.[34]

2.3. Blockchain-based Deep Learning

The utilization and secure distribution of deep learning methods are criteria that blockchain technology can fulfill. Similarly, the major objectives behind the incorporation of deep learning and blockchain are auditability, data verification, authentication of results, authenticity, ownership tracking, utilization, and assurance of fairness.

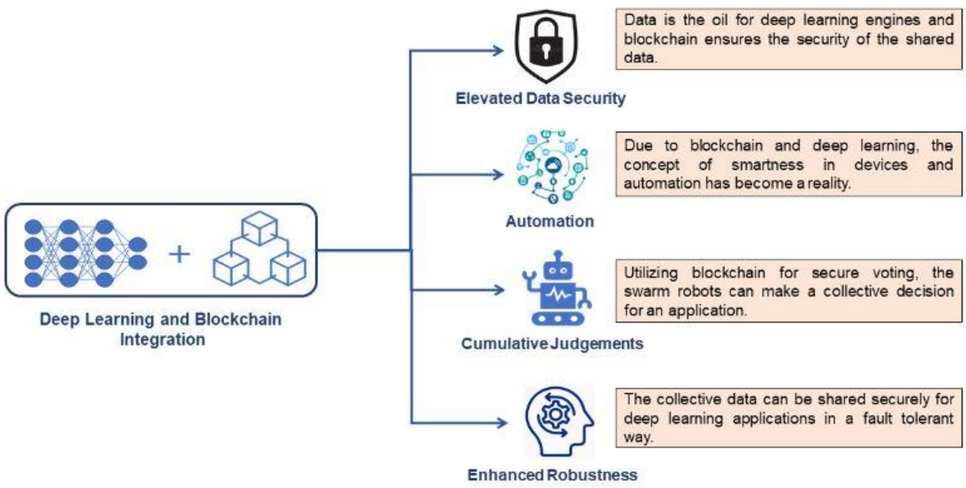

Fig. 3: The combination of deep learning and blockchain technology yielded benefits.

Deep learning methods are fed a huge amount of data with a variety of instances, which the models utilize to learn the attributes and provide an output with likelihood vectors. Even though deep learning models operate remarkably well on original data, the data quality still counts in many real-world settings when it comes to prediction.[35] The blockchain is a decentralized and verifiable global system in which all nodes in the network can store and exchange information.

Table I Features Of Blockchain And Deep Learning In The Healthcare System

Deep Learning	Cybersecurity	Immutable	Transparent	Integrity
Blockchain	Intensive of data	Scalable	Layered	Resource intensive
Potential results	Upgraded data security	Learning strategy flexibility	Update of the collaborative model	Increased scalability

Table I illustrates some of the major characteristics of blockchain and deep learning that aid in the development of deep learning apps [25]. The primary classes that benefit from such connectivity are highlighted in Figure 3. Blockchain and deep learning can work together to create a robust, durable, and decentralized framework for the vital information that deep learning-driven apps will collect, analyze, and use.

3. Research Challenges And Opportunities

This section briefly reviews some of the research problems and potential related to the integration of deep learning and blockchain technology in the healthcare system. Platform scalability, affirmation of secure exchanging data, transaction processing lag, platform connectivity support, the vast quantity of data gathered from sensors, and computationally intensive consensus processes are all major roadblocks to the successful incorporation of these technologies.

3.1 Platform Scalability

The availability of different variations and configurations of blockchain technology is a key concern for architects creating deep learning systems. A robust blockchain network can manage the high number and speed of transactions produced by a variety of users. To execute deep learning-based services focusing on healthcare via cellular networks, a large blockchain network would require a comparable number of accounts. The widespread use of blockchain will result in many issues, primarily linked to user need for internet access, data speed, velocity, and amount of transactions produced by participants.

3.2 Data Validity and Secure Sharing

Due to state-of-the-art decryption and encryption mechanisms employed by private blockchain systems, data exchange between healthcare industry users including nurses, doctors, and patients can be anonymized. Users are concerned about data protection, privacy, and confidentiality as IoT and wearable devices become more prevalent in healthcare networks. A multi-layer blockchain design that enables information fusion and improved analytical verification for user groups may help users securely share data. Furthermore, during the current COVID-19 pandemic, the verification and secure exchange of immunity passports amongst authorized users via a smart contract have become a prerequisite to meet healthcare system criteria for establishing a feasible, safe, and fault-tolerant system. The ability of blockchain to validate and archive immutable data in real-time, in particular, brings up the possibility of ensuring data authenticity. Many research initiatives use the blockchain network as their foundation. It enables healthcare people, as well as developers and experts, to share knowledge and validate data in new systems securely and reliably.

3.3 Structural Enhancement and Storage Capacity

Deep learning is a resource-intensive and data-intensive method for assisting in the solution of a variety of real-world issues. The goal of blockchain technology is to make the data it stores highly secure, unchangeable, verifiable, transparent, and visible to authorized parties. It is economically advantageous to use a deep learning-based method to assess the performance of blockchain systems systematically. Such a method may be used to examine the present architecture of the blockchain and suggest ways to improve it. D However, when new blocks are added to the current network, blockchain symbolizes an ever-growing record.

4. Methodology:

4.1 Carando in Healthcare service:

Cardano is a Web 3.0 upcoming internet system built on a publicly listed blockchain-based crypto network. In contrary to Ethereum, which employs proof-of-work techniques, Cardano utilizes the Ouroboros proof-of-stake system. Proof-of-stake blockchains consume much less energy than proof-of-work blockchains. Cardano launched decentralized healthcare services, such as a smart contract update and the capability to create decentralized apps.

4.2 Design:

Cardano's structure is centered on levels. Cardano becomes more adaptable due to these Layers, and it may also handle complicated user privacy issues. As a result, it is feasible to incorporate regulatory and supervision to transactions while maintaining privacy and security. Cardano employs two different sorts of components to store healthcare information. One type is a system that allows you to deliver data and track its flow. The other kind is for information stored on the patients' causes and conditions. Scalability is another major concern with blockchains. One of the primary objectives of the Cardano development phase was to offer the needed scalability.

Scalability is one of the most significant concerns with existing blockchain technology like Ethereum. As a result, Cardano made it a priority to solve this problem. Cardano aims to achieve this by developing a more efficient consensus algorithm that can match the throughput of traditional financial systems. It's known as Ouroboros. Instead of the entire blockchain, only a small number of trusted nodes are accountable for keeping the record in this consensus mechanism. This responsibility is limited by the amount of time that has gone. After that, the obligation will be passed on to someone else.

4.3 Implementation

The blockchain smart contract framework has been used to create and implement several medical processes containing certain medical activities. These responsibilities include arranging for medical transportation and hospital placement for patients. The goal of creating these medical smart contracts is to make it easier for doctors, patients, and healthcare organizations to overcome bottlenecks in the administrative process. Medical data acquisition, evaluation, and administration of complicated healthcare data and processes will be aided by this system.

4.3.1 Blockchain-based smart contracts in ambulance service:

The paper suggests focusing on a specific concern related to patients' hospitalization during a pandemic. A way for utilizing information technology to assist in ambulance truck routing decision-making during hospitalization is offered. It is founded on the problem being split into 2 tasks:

1) deciding whether or not to be admitted to the hospital and selecting an ambulance vehicle
2) Choosing a hospital whereby the patient should be transferred using the chosen vehicle.

Numerous parameters are calculated for each task, including the accessibility of empty places (beds) in clinics, the mean transportation time, the number of emergency vehicles, and the cost of medical care, as well as the qualitative variables related to the psychoemotional load on emergency responders, patients, and medical personnel.

In many nations, the pandemic produced by the COVID-19 virus has provided a burden to healthcare systems. After a sick individual is discovered, one of the most critical jobs is to get the patient to a hospital as soon as possible. Many factors must be considered when deciding whether to transport a patient to the hospital, such as the accessibility of beds, hospital workers, and prescription drugs needed by the treatment regimen, testing devices on the ambulance group, range to the hospital, ambulance automotive spots, clinic and ambulance staff psychophysical state, and the patient's response to hospitalization. It is proposed that blockchain and smart contracts be used to quickly track the current state in this effort. Blockchain technology makes it possible to preserve patient health records and restrict entry to them to only authorized personnel. It's also feasible to save the present state based on the primary parameters that can be used to describe the scenario. Smart contracts in the form of decentralized applications could be used to calculate the coalition game's outcome and aid decision-making during hospitalization.

4.3.2 Initial Diagnosis

The initial step is to determine whether or not hospitalization is required, as well as to choose an ambulance vehicle from a set of possible vehicles (Fig. 4).

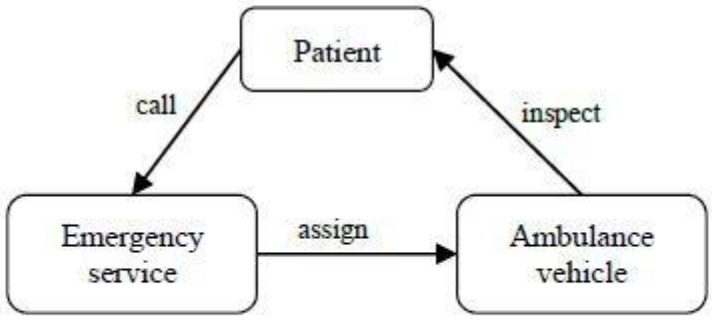

Figure 4: Initial call dispatching problem.

A quick survey is completed after receiving a call from a patient to determine the likelihood of a specific ailment. In addition to questions regarding the major symptoms, the survey may include questions about concurrent illnesses, age, gender, and past contacts. The patient's location, as well as his or her medical insurance, are also mentioned. The dispatcher service should evaluate the requirement for hospitalization after gathering data. Then, depending on need and accessibility, an ambulance is chosen that has all of the essential equipment and medications for a preliminary assessment and possible hospitalization. Dispatchers are provided with a decision support system that evaluates the requirement for hospitalization and selects a suitable ambulance vehicle as part of the proposed methodology.

The following information was received from the dispatcher: Number of calls received every day; the average intensity of patients requiring hospitalization; mean distance from the patient's place to the hospital; Empty beds in clinics; average wait time for ambulance bookings in the event of hospitalization Ambulance Cars Provide the Following Information: Location, Staff professionalism, Ambulance apparatus, Staff working time & Data from Ambulance Cars. It is proposed that the problem of selecting an ambulance for hospitalization be expressed as a decision problem. Furthermore, if an ambulance is now on the way to the patient, all that is left is to address the dilemma of choosing which hospital to go to. Otherwise, after selecting a hospital, the characteristics listed above must be used as restrictions in the selection issue.

4.3.3 Selection of hospital

The second duty is to select the hospital to which the patient will be taken. Figure 5 displays the process of transporting a patient to the hospital.

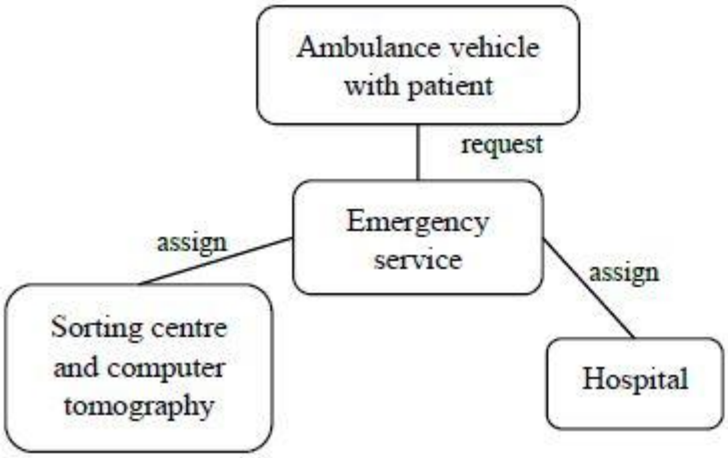

Figure 5: The process of transporting a patient to the hospital.

When an ambulance is dispatched to a patient, the ambulance crew is in charge of the patient's condition. They must use their equipment to perform an initial evaluation and determine whether the patient requires immediate hospitalization, transportation to a sorting center, or more testing. Computer imaging of the lungs, for instance, may be required to verify the diagnosis and the necessity for hospitalization in the case of COVID-19. When considering hospitalization, find a facility with available beds and all of the required tools to treat the sufferer with the seriousness of the disease.

Many parameters must be taken into account when addressing this problem, including Parameters of Ambulance and Patient: Condition of the patient; Location of the ambulance. Healthcare system objectives; road traffic; free seats, lab parameters; service time for one client; service line; resources; disinfection, and cleaning time after service are all parameters used by the dispatcher.

4.3.3.1 Parameters in the hospital

Accessible treatment procedures and scripts; Resources available (medicines, device); Service duration for one patient; Buffer size; Bed amount; Accessible treatment procedures and scripts; Resource availability (equipment, medicines,) This contract serves as a breadcrumb trail for people looking for their medical records in the system. In the form of citations to PPRs, it keeps a record of all of the participant's previous and present contacts with other nodes in the network. For example, patients' SCs would be jammed with citations to any healthcare practitioners with whom they came into touch. Clients and third parties with whom their consumers have been permitted to share data are more willing to recommend providers. SC stays in the network's distributed locations, providing critical recovery and backup functions.

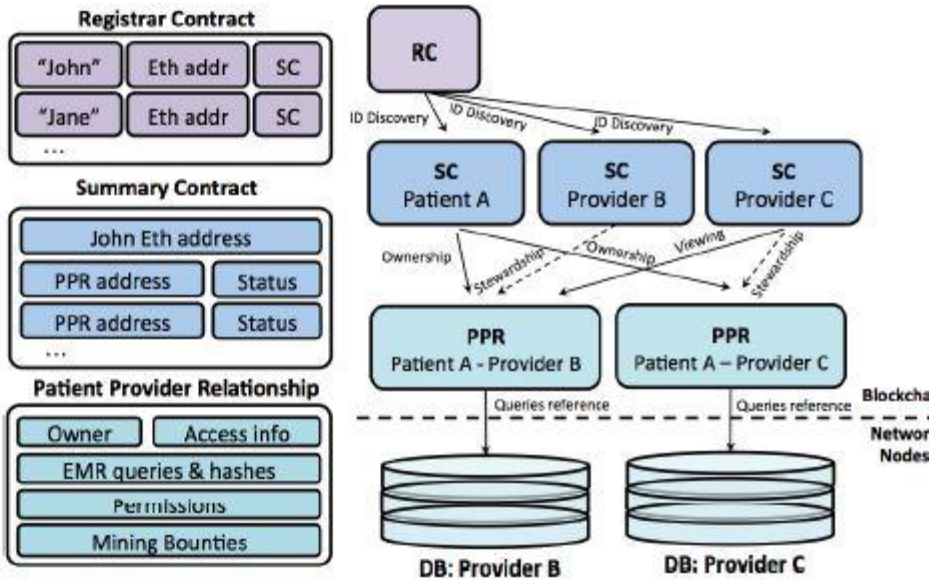

Figure 2. MedRec smart contracts, with data content for each contract type.

5. Smart Contracts from Carando blockchain for Healthcare

We construct smart approximations of current health records that are kept on the system within specific nodes using Carando smart contracts. We create contracts that provide metadata about record ownership, permissions, and data quality. Cryptographically signed rules for controlling these characteristics are included in our system's blockchain activities. Only legal transactions ensuring data alternation are used by the contract's state-transition functionalities to carry out rules. As soon as a health history can be stored digitally, these laws can be built to implement any system of regulations governing it. For instance, a policy might require patients and healthcare professionals to send distinct authorization before providing third-party viewing rights. For complex medical workflows, we created a solution based on blockchain smart contracts. Smart contracts were created to manage data access permissions across different stakeholders in the healthcare ecosystem and to support various medical processes.

5.1 Database:

Smart contracts, which are based on blockchain technology, allow us to regulate and track specific state transfers. We keep track of patient-provider connections using Carando smart contracts that relate a health file with observing authorizations and data recovery instructions (basically information pointers) for outer server execution. To prevent tampering, we entail a hash code of the documentation on the blockchain.

Patients can approve record exchange between doctors, and providers may add a new document related to a specific patient. In both circumstances, the person obtaining new information gets an electronic notification and has the opportunity to verify the new record before it is accepted or refused. This keeps participants informed and involved in the development of their records. This system prioritizes usability by including a defined contract that collects references to all of a user's patient-provider connections, giving a single standard for health records updates. We handle identity verification through public-key cryptography and a DNS-like system that links an already existent and commonly recognized form of ID, including a user's name or SSN, to the user's Carando address. A syncing technique handles "off-chain" data transfers between patient data and provider data after referencing the blockchain to check permissions through our database authenticator.

5.2 The Process for Issuing and Filling of Medical Prescriptions

The major goal is to reduce the error rate caused by doctor misinterpretations by eliminating excessive waiting times, removing the fraud aspect from the system, and streamlining the healthcare prescription management procedure. A doctor prescribes a medicine for a patient and uses a smart contract to add it to the patient's medical records. The pharmacy then has access to this prescription via the Carando blockchain smart contract, thanks to approval from the main doctor and the patient. After obtaining the prescription, the pharmacy provides the medicine, which is then posted to the patient's medical record via smart contracts, together with the medicine's expiration and dose use, and the medicine is available for collection by the patient. The smart contract capabilities let doctors and pharmacy retailers organize medicine satisfaction. Following a patient's appointment, doctors spend less time discussing pharmaceutical requests or conversing with drug shops in general.

5.3 Sharing Laboratory Test/Results Data

The major goal is to communicate information via blockchain smart contracts, which will allow labs, doctors, medical centers, and other partners to efficiently acquire and exchange a patient's therapeutic data with other stakeholders. Assume a scenario in which a patient goes to a lab to have a blood test. The lab will enter the outcomes into the patient's medical record after processing, and the patient will receive notifications through the Carando blockchain, including a notice that the test's processed outcomes are available, as well as the option to allow the lab to encapsulate the data and put it on Carando blockchain.

5.4 Data Flow for Healthcare Reimbursement

The main goal is to speed up the payment procedure for the healthcare system. Doctors will be ready to progress with care more swiftly instead of having put their patient's treatment on hold while expecting the payer to reply. The entire process will be monitored by the implementation of computerized smart contracts. Minimizing, and eventually eliminating, the error-prone manual evaluation and response to prior authorization requests, as well as reducing appeals prompted by the improper perception of manually drafted prior authorization documents.

The Health Insurance Company publishes its policies as blockchain smart contracts, which are utilized to determine permission. A supplier then requests prior authorization for a doctor's appointment, therapy, or medication to the blockchain. The smart contract for a payer's health policy generates automatic authorization based on the patient's health data held on the Carando blockchain and the data in the request. The approval information will be promptly returned to the supplier. The patient, and also any laboratories, pharmacies, experts, or other entities to whom the patient has granted access, might also check the insurance approval.

5.5 Carando-Based Smart Contracts for Clinical Trials

The key objective is for users to be able to perform clinical trial-related smart contracts on the Carando network, leading to safer drugs and greater public interest in medical research. We will use smart contracts to manage metadata such as protocol identification, preset research details, filtering, and enrollment records during this process. A drug industry searches the Carando blockchain for metadata to find potential candidates for clinical trials. The organization then sends a message to a subset of patients, along with an application that allows them to examine their medical information, such as any applicable laboratory testing results.

5.6 Basic Outpatient Surgical Procedure

In a busy hospital, the procedure involved with surgery might be a major strain. The EHR Medical Workflow Platform is designed to suit the requirements of busy practices by converting a difficult system into a simple, step-by-step workflow. The Carando blockchain smart contracts Medical Workflow platform can incorporate the practice. This permits billing, administrators, and other duties to assist the process from pre-operative through post-operative patient administration. The information is then smoothly incorporated into the patient's previous surgical file. It would be feasible to record patient permission and an initial condition of the patient using the smart contract characteristics. Different activities are included throughout the post-operative procedure in our process. Pre-approvals, health authorization, surgery planning, pre-operative diagnostics, and consent documentation are all part of this process. The visit is documented, the treatment is recorded, and the payment is made throughout the procedure. This might be handy for looking through previous surgical cases or operations that were postponed.

6. Conclusion

In this paper, we look at how a blockchain structure can be applied to the Carando blockchain. This paper discusses Carando smart contracts and how they can be used to construct intelligent approximations of current health records stored in specified network nodes. The contracts are designed to include information on data ownership, rights, and integrity. Blockchain is the potential of providing a stable and transparent structure for keeping digital health records, resulting in better patient care and lower treatment costs. This paper explains how smart contracts can be used to establish interoperability in the healthcare system, and also how eliminating middlemen can save money and improve the system's reliability. a fully user-owned and run integrated cloud system, and the ADA token is a share of that ownership. Cardano is experimenting with smart contracts as a significant technology aspect that, if successful, will enable the network to engage in a broader variety of dApp use situations. The Cardano open-source software network connects a global network of decentralized computers to create Cardano has been capable to build up a large decentralized user base, resulting in fast network expansion.

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