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Survey on Electronic Health Record Management Using Amalgamation of Artificial Intelligence and Blockchain Technologies

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Abstract

In the present times, the healthcare sector has seen an enormous growth in the usage of technology ranging from EHRs (electronic health records) to personal health trackers. Currently, there is a need for managing EHRs effectively with respect to storage, privacy and security measures. State-of-art technologies such as blockchain and artificial intelligence (AI) are applied in the healthcare domain. Innovation in AI is steadily advancing and is finding its place in different industries. The integration of blockchain and AI looks promising as there are several benefits. Blockchain can make the AI more secure and autonomous whereas AI can drive the blockchain with intelligence. The objective of this article is to explore the uses of blockchain as well as AI technology in the field of healthcare. We aim to survey the advantages, issues and challenges of integrating blockchain with AI technology, including future research directions in the healthcare domain. In this study, Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) rules and an efficient searching protocol were used to examine several scientific databases to recognize and investigate every important publication. A solid systematic review was carried out on integration of blockchain and AI in the healthcare domain to identify existing challenges and benefits of integrating these two technologies in healthcare. Our study found that the integration of AI and blockchain technology has a potential to provide several benefits in terms of performance and security which conventional EHRs lack. The inherent benefits of blockchain and AI together are limitless, but the bare outcomes based on blockchain powered by AI technology are yet to be obtained. In addition, the outcome of our detailed study may aid researchers to carry out further research.

Keywords

Electronic health record; Decentralized AI; Machine learning; Healthcare.

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1 Introduction

A new change in the technology outlook is shifting towards artificial intelligence (AI) and blockchain. AI offers insightful and dynamic capacity to computers while blockchain provides a decentralized, immutable data storage. These two technologies are consolidating and transforming different areas including medical care, agriculture, supply chains, land, retail, etc. AI and blockchain together will provide another dimension to the healthcare sector in near future.

AI and blockchain have their own set of advantages and disadvantages. Performance issues, energy utilization, scalability and privacy are some of the problems faced by blockchain whereas AI has data quality and interpretability issues. These two different technologies have various advantages when combined. AI and blockchain have common requirements such as security, data analysis and trust, which can empower each other. Additionally, blockchain can store the decisions of AI, which aids to analyse behaviour of AI, making it more straightforward, reasonable and reliable. Artificial intelligence can upgrade the development of the blockchain to make it safer, energy-saving and more proficient.

Amazon, Apple, Google and Microsoft, as well as a huge number of new companies, are effectively investigating AI for clinical applications, planning to work on more successful utilization of patient information, determination exactness and making better proposals dependent on proof-based examination discoveries, in addition to other properties. These applications come on top of progressions in automated medical procedures and advances conveyed through mobile phone applications. As per Accenture, essential AI-based healthcare applications could save the US medical services economy $150 billion every year by 2026 (Bohr and Memarzadeh, 2020).

1.1 Literature review

Xia et al. (2017) proposed a system for properly administering and protecting health records. It is a system based on blockchain designed for the efficient administration and safeguarding of shared patient health data in huge data units. The data stored in the system are kept secure using cryptographic keys and authentication. Yet, there seems to be concern regarding the system's susceptibility to data exposure. Azzaoui et al. (2020) tried to address standard Electronic Health Record (EHR) system privacy and security problems and meet the requirements of patients, caretakers and third parties. They used algorithms and smart contracts to create a strong public health system. Hathaliya et al. (2019) introduced a biometric-based validation strategy for securing EHRs. They proposed a framework in which data from wearable devices are collected and stored in cloud databases. They used biometric verification to secure the safety of EHRs.

Wehbe et al. (2018) suggested a blockchain AI model describing the prerequisites for a computer-based diagnosis system utilizing the healthcare records. To provide diverse healthcare services, authors suggested the use of AI-enabled drones using private blockchain network. Zhaofeng et al. (2020) presented a blockchain-based framework for edge computing data management systems. Jabarulla and Lee (2021) described a blockchain and AI-based architecture for dealing with COVID-19 pandemic-related challenges.

AI is fit for executing convoluted computational capacities and rapidly assesses immense volumes of patient details. Nonetheless, a few specialists (Zhang et al., 2017; Wang et al., 2018) say that we need to be careful in utilizing AI in medical services, especially in places that might impact a patient's prosperity, considering the incredible capacities that AI can give, which has shown that, speedier than an individual, it can execute numerous dynamic and intellectual capacities. This amalgamation of AI and blockchain plays a vital role by storing EHRs in a block manner and comparing them with previous stored data. Decentralized AI is a relatively emerging concept. Decentralized AI essentially combines AI and blockchain technology. Decentralized AI enables authorized, securely shared and digitally signed storage of documents on the blockchain in a decentralised and distributed manner, without the need for intermediaries (Vyas et al., 2022).

So far, the current literature on the amalgamation of AI with blockchain in the healthcare sector lacks extensive studies and surveys. Most of the present literature discusses AI and blockchain technologies in isolation and their applications in different domains (Lin et al., 2018; Xia et al., 2017). A few recent studies have reviewed AI with blockchain technology and their effect on various sectors (Aguiar et al., 2020; Tagde et al., 2021). Yet there is an absence of summarizing the work on the amalgamation of AI and blockchain. Therefore, this paper examines the practicality of the integration of blockchain and AI technology thoroughly and provides various insights on the same. Table 1 shows the key benefits of integrating blockchain with AI technology.

The contributions of this study can be summed up as below:

- It gives a brief overview of blockchain technology fundamentals and vital features and how these features influence the AI.
- It discusses the benefits of integrating blockchain with AI that helps in developing a decentralized ecosystem.
- It discusses a comprehensive taxonomy focusing on blockchain and AI for decentralized process and applications.
- It identifies the challenges of blockchain-based AI applications and discusses future research directions.

Table 1. *Key characteristics and advantages of integrating blockchain with AI.*

AI	Blockchain	Integration benefits
Centralized	Decentralized	Improved data security
Changing	Deterministic	Enhanced trust
Probabilistic	Immutable	Collective decision making
Volatile	Data Integrity	Decentralized intelligence
Resilient to attacks	Data, knowledge and decision-centred	High efficiency

The paper is organized as follows. Section 2 discusses the research questions, article search and article selection related to the topic. Section 3 gives an insight on the applications of blockchain and AI technology respectively. Section 4 discusses the integration of AI and blockchain technologies and their taxonomy. Section 5 focuses on open issues and future research directions of amalgamation of AI and blockchain. The last section, i.e., Section 6 concludes the topic.

1.2 Electronic Health Records

EHRs are the most widely recognized and commonly created patient records to store patient information digitally (Dash et al., 2019). A patient's EHR incorporates personal details, health related constraints, clinical history and drug prescription information. Healthcare organizations produce EHR information dependent on medical care experts and research centres (Chenthara et al., 2020).

Apart from EHRs, Personal Health Records (PHRs) are records created and claimed by patients, where each patient allows access to his/her PHR data based on the need. A PHR is generally created utilizing mobile phones and different Internet of Things (IoT) based wearable clinical gadgets. It contains data on a patient’s overall health, such as pulse, internal heart level, sensitivities, immunization history and past medical procedures. PHRs are useful for remote assistance and reduce response time in the event of a disaster. Healthcare experts make recommendations to patients based on information available in both EHR and PHR (Fang et al., 2021; Pilares et al., 2022). Figure 1 shows the cycle of EHR data storage.

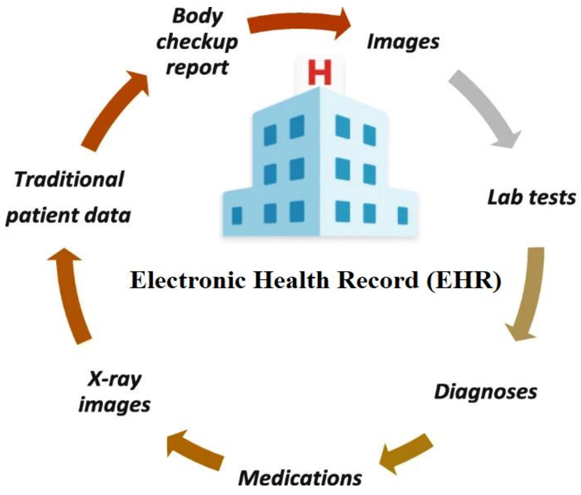

Figure 1. *EHR cycle. Source: (Hussien et al., 2019, p. 2).*

Benefits of EHRs

EHR has numerous advantages for the medical services environment:

- Easy access to information in an organized framework reduces operational and regulatory costs and the possibility of clinical errors.
- A centralized repository of a person's health data boosts data mining and analysis abilities.
- Better availability of EHRs enhances patients' responsibility for their health.
- Transparent data accessibility enhances doctor proficiency and the nature of treatment.
- It makes health information more accessible, decreases the duplication of tests, lowers treatment delays and educates patients to make better decisions.

Issues related to EHRs

- **Limited information sharing:** Today's dominant EHR systems limit the free movement of patient data across multiple segments. Most retailers impose interface fees for transfer of information. The healthcare framework incurs additional costs because of clinical test duplication caused by poor data accessibility.
- **Lack of significant knowledge:** In addition to the benefits of knowledge discovery, information storage is severely limited by the inaccessibility of entire information and the reluctance of EHR vendors to create customized interfaces.
- **Interoperability:** The global healthcare network has been widely distributed. The various components of the EHR framework should interact and communicate with one another. This is made possible by deploying an interoperable technique for these EHR systems. Interoperability of diverse EHR frameworks improves work process execution, improves the nature of medical services, and reduces duplication and expenses. (Puneeth and Parthasarathy, 2021).

2 Research methodology

A systematic review is a technique for recognizing, assessing and understanding the existing research pertaining to the topic under consideration. A systematic literature review is carried out with a focus on blockchain and artificial intelligence in the healthcare domain using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009) as shown in Figure 2. Systematic review consists of research questions for better understanding of the technologies with respect to healthcare. All the articles in this review were considered from authentic sources such as IEEE, PubMed, ACM, Google Scholar and Science Direct.

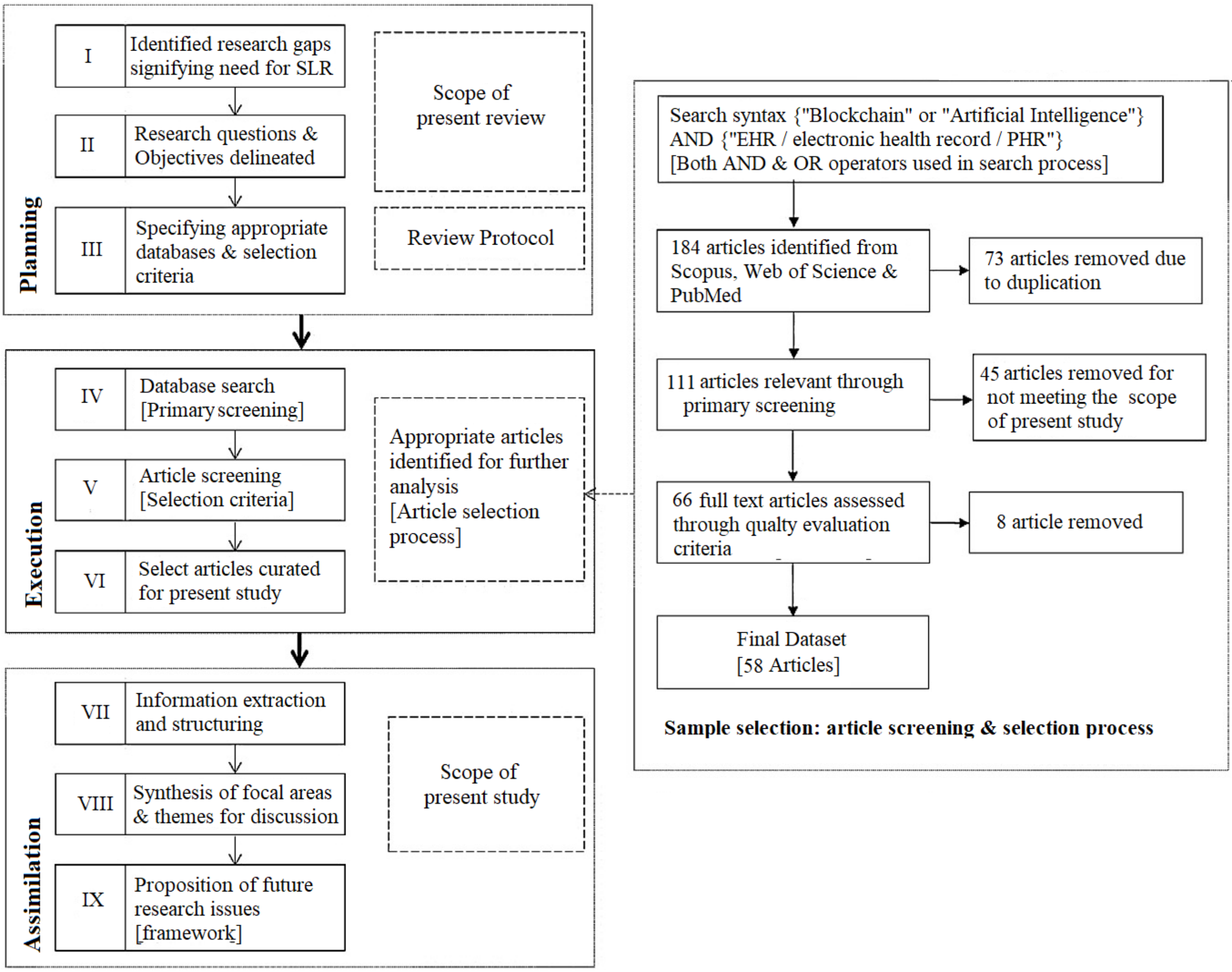

Figure 2. *PRISMA flow diagram of article selection process.*

During the literature review process, the following activities were executed:

- research questions,
- search strategy,
- article selection,
- data abstraction.

Research questions

The research questions that were considered during the systematic literature review are shown in Table 2.

Table 2. *Research questions.*

No.	Research questions	Objectives
1.	What are the requirements, benefits and limitations of the electronic health record?	The aim is to explore the advantages and limitations of using the EHRs.
2.	What are the different avenues in healthcare where blockchain technology can be applied?	The goal is to examine various potential applications of blockchain in the field of healthcare.
3.	What is the taxonomy for AI applications with Blockchain?	The major goal of the taxonomy is to provide a conceptual model for categorising and summarising ideas from a corpus by using organisation to make concepts clear and generate connections.
4.	How might blockchain improve healthcare applications using AI?	The goal is to look at how blockchain technology may enable AI-based healthcare to become more reliable by addressing privacy and security concerns.
5.	What developments in blockchain technology support AI in the healthcare industry?	Another goal is exploring the blockchain innovations that might integrate with AI-based healthcare.

Search strategy

The strings that were used for searching were "Blockchain", "Artificial Intelligence" and ("Electronic health records") OR ("Semantics") OR ("interoperability") OR ("Medical Records") OR ("PHR") OR ("EHR") OR ("Health records") for identifying the related articles from various repositories and sources such as IEEE, PubMed, ACM, Google Scholar and Science Direct.

Article selection

To select the suitable research articles for the final review process, several exclusion and inclusion steps were executed. The following inclusion criteria were considered: blockchain technology in electronic health record, AI in electronic health record, interoperability issues in EHR, data semantics in EHR. In the exclusion process duplicate articles, partial information articles and articles irrelevant to the topic of discussion were removed. Table 3 shows the inclusion and exclusion criteria applied in the current study.

Data abstraction

Some of the design parameters were selected to complete the data abstraction process, such as type of blockchain architecture, smart contracts, data heterogeneity, type of EHR and interoperability solutions. The advantages, limitations and future research directions using blockchain and AI were identified and presented under specific topics.

Table 3. *Review criteria of inclusion and exclusion.*

No.	Inclusion criteria	Exclusion criteria
1	Published in peer reviewed journal	Non- English publications
2	Articles published between the years 2016 and 2022 (inclusive of both the years)	Book chapters
3	Articles which are relevant to blockchain solutions for AI based healthcare systems	Articles that do not focus on blockchain solution for AI healthcare applications
4	Publications that relate to research queries	Duplicate publications

3 Background

3.1 Blockchain technology

Blockchain is a series of blocks that include a list of complete and correct transaction records. The blocks are linked together by a connection (hash value) to the previous block, forming a chain (as shown in Figure 3) (Liu et al., 2018). The initial block of the blockchain is known as the genesis block. Figure 4 shows the structure of the block, which consists of a block header and other attributes.

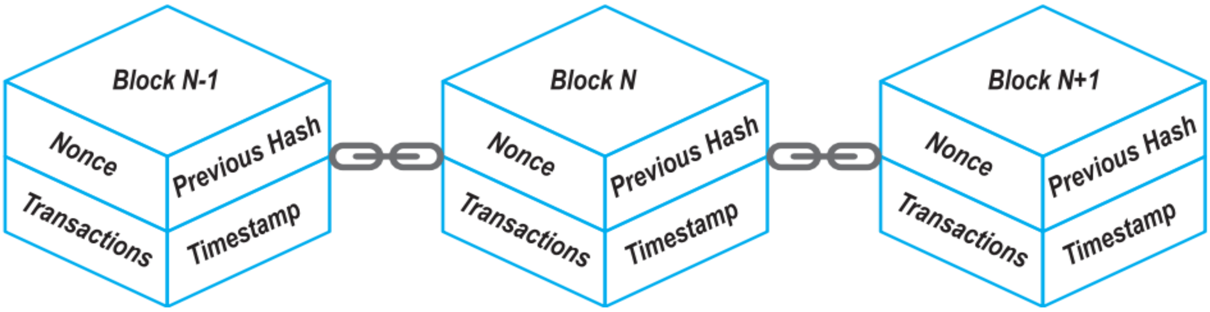

Figure 3. *Standard blockchain structure. Source: (Mamun, 2022, p. 3).*

The blockchain idea was first presented in Bitcoin with regards to decentralized electronic money. The popularity of Bitcoin stems from the usage of blockchain to provide reliable and safe transactions across an untrustworthy network without relying on any trusted third party (Chen and Lin, 2018). Blockchain technology has gained popularity due to its rising value in a variety of applications ranging from information storage to financial business sectors, security, IoT and medical services (Shao et al., 2018; Siyal et al., 2019).

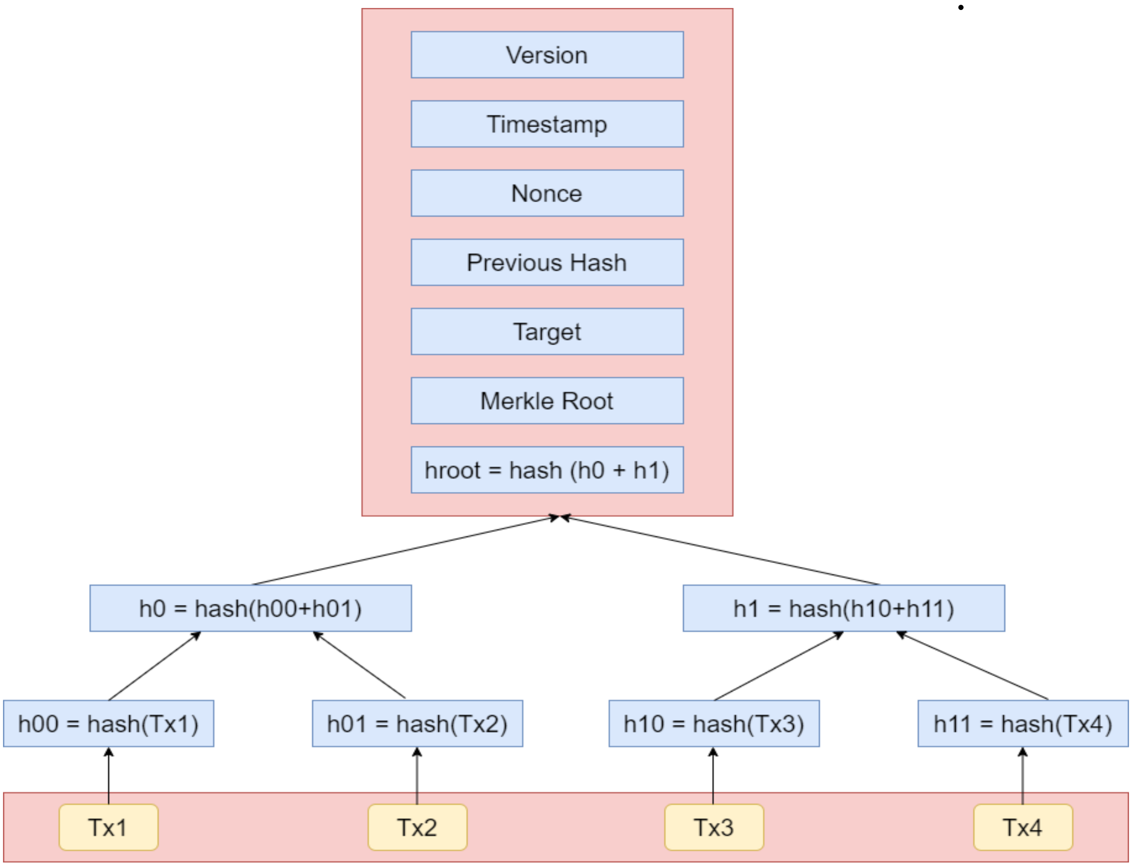

Figure 4. *Basic diagram of block with several modules.*

Blockchain technology has also demonstrated tremendous potential in biomedical science. Even before beginning a clinical test, it may be possible to store all clinical approvals, timelines and conventions on a blockchain. As a result, key preliminary clinical details will be more accurate, secure, time-phased and successful in operation as well as deployment (Ivan, 2016).

Types of blockchain and its application in healthcare

Before data can be added to a blockchain, its users must reach a consensus. A consensus is an agreement among the users of blockchain. A notable consensus algorithm is Proof of Work (PoW), which is widely used in the Ethereum and Bitcoin blockchain network. Table 4 shows a comparison between different types of blockchains. Blockchains can be classified into three types based on which members are permitted in the agreement calculation (Ahram et al., 2017):

- **Public**: anybody can take part in the agreement calculation. Examples: Bitcoin and Ethereum (Aguiar et al., 2020).
- **Consortium**: a select (or consent) gathering of users can take an interest in the agreement calculation. Examples: Hyperledger Fabric (HF), Corda (Paul et al., 2021).
- **Private**: a group of users works on a specific algorithm and controls the addition of new information to the blockchain network.

Table 4. *Comparison between types of blockchain on certain key features.*

No.	Key features	Types of blockchain		
		Public	Consortium	Private
1	Consensus protocols (CPs)	Participation by anyone	Select only genuine participants	Only for single participants
2	Decentralization	Yes, it was distributed equally to all entities	Partial distribution	Not distributed
3	Transparency	Yes, data publicly available	It can be public or can be secured for a specific entity	It can be public or can be secured for a specific entity
4	Immutability	It is tamperproof	Can be tampered with	Can be tampered with

Table 5. *Blockchain applications in healthcare domain. Based on (Agbo et al., 2019; Mamun et al., 2022).*

Applications	Summary
Electronic Health Records	Without human intervention, the integrity of a digital EHR on a distributed ledger of blockchain is assured from the point of data synthesis to the point of data retrieving.
Clinical research	With reference to clinical research, blockchain presents a decentralized supporting framework for any sharing of information that might occur. Data can be safely shared among a team of researchers using this.
Medical fraud detection	Blockchain's immutability characteristic helps in detecting fraud by preventing duplicate or altered transactions, resulting in a transparent and safe transaction.

Applications	Summary
Neuroscience research	Blockchain technology has the potential to be used in several cutting-edge applications that incorporate brain enhancement, brain simulation and brain thinking. A medium must be used to store the entire digitalized human brain, and here is where blockchain innovation comes into play.
Pharmaceutical industry and research	The pharmacy supply chain industry is closely monitored by blockchain, thanks to its power of thorough tracking; ownership and origin of the drug are frequently determined at each stage to prevent counterfeiting and theft of goods.

Electronic Health Record

The most well-known healthcare applications of blockchain technology are in EHRs. Patients may visit a different hospital every time, which leaves their health data scattered across several organizations. Due to this, maintaining a patient's lifelong records in one place is a major problem (Tanwar et al., 2020). One of the solutions is to share the health records across multiple organizations. Sharing health records has significant challenges, such as lack of control over information, information integrity, validity and security of clinical data during EHR sharing. To overcome this challenge, the MeDShare application used blockchain structure for sharing healthcare data among unreliable entities with specific conditions (Shrier et al., 2016; Kuo and Ohno-Machado, 2018). The use of blockchain technology would leverage the health record verification, correctness, improved diagnosis and care (Xia et al., 2017).

Secure IoT devices

Security is a critical problem in the health IoT, in terms of both protecting patient information and preventing its manipulation to produce false information. The data security of IoT gadgets could be enhanced using blockchain technology (Khan et al., 2020a). Patient data are more valuable and safer in blockchains because they provide hash and cryptographic functions that ensure source data are secured. It is generally difficult to change patient information once it has been recorded on the blockchain record because doing so would necessitate changing all the stored versions (Aguiar et al., 2020).

Transparent supply chain

Clinical products need to be certified by the healthcare sector, which is a crucial step before a patient may receive a diagnosis. Using a blockchain-based framework, customers can track items from the manufacturing facility through every stage of the retail network, providing them with complete understanding and clarity over the item they are purchasing (Paul et al., 2017; PwC, 2017).

Protection to electronic healthcare system

To ensure the validity, privacy and reliability of health records and health reports that contain all of a patient's critical information, the healthcare organizations need to have a clear understanding of access control, validation and integrity of information. Role-based consent should be introduced for handling and transfer of the sensitive health information to provide protection and privacy. Blockchain provides a practical framework for creating a private/public organization which guarantees information access only to authorized users (Hussien et al., 2019; Dubovitskaya, 2017). Recently, researchers have investigated the potential of blockchain to create a reliable, decentralized network for information exchange.

3.2 Artificial intelligence

AI innovation began in 1956 and has experienced pinnacles of improvement in 1956-70, 1980-90, and from 2000 to the present. In 1959, the introduction of machine learning (ML) led to the peak of development during the first generation. The USA and Japan were devoted to AI research during the 1980-90s, which advanced to the second generation. The major developments such as deep learning, enormous growth of data and computing power led to the third generation (Rockwell, 2017). Computer vision, natural language processing (NLP), swarm computing and smart drone systems are some of the salient technologies of AI which are useful in different industries such as agriculture, healthcare and IoT (Baron, 2021). Table 6 presents several applications of AI technology in healthcare.

AI is described as the science and design of smart frameworks that can process vast amounts of data before making them available to end users (Lin et al., 2020). These frameworks use a variety of proposed algorithms, as well as vast volumes of information, to respond to questions or provide answers. AI technology supports us in our routine tasks all around (Krittanawong et al., 2019). The introduction of automated vehicles, advancements in medical research and personal wearable technology have demonstrated the enormous potential of the technology and how far it has progressed over the course of many years. Medical care is probably going to stay the first industry where AI can have an impact on individual lives (Liu et al., 2018).

Table 6. *AI in various healthcare domains.*

Diagnosis and treatment design	AI is increasingly being used in healthcare to suggest treatment strategies for patients. AI can develop greater techniques for better treatment by studying data from earlier patients. AI can spot key indicators of disease more precisely and quickly with the use of medical imagery such as X-rays, CT scans, ultrasound etc. It benefits patients by allowing more accurate disease detection and treatment options.
Electronic Health Records	AI has the potential to read medical records and deliver information to doctors. Algorithms can use EHR to evaluate the probability of an illness based on past data and family medical history. AI algorithms are capable of learning using enormous volumes of data, and throughout this process, the algorithm develops a system of rules that correlates its findings to the final diagnoses. When new patient data are fed into AI, it can analyse the patient based on past data and identify the possibility of a condition or disease (Baron, 2021).
Drug interactions and discovery	Drug interactions pose a risk to patients who take several medications at the same time; the risk increases with the number of prescriptions used. It is difficult to deal with every drug interaction and its ill effects; however, with the help of AI algorithms, drug interactions and their side-effects can be extracted from past clinical studies. ML approaches enable significantly shortened drug discovery times.
Dermatology	In healthcare, dermatology is heavily dependent on medical imaging. Deep learning techniques have greatly improved the task of image processing. Dermatology uses three types of images: micro images, macro images and contextual images. Deep learning has made significant progress for each of these image types.
Radiology	AI is being applied in the field of radiology, and diseases are identified in patients using MR imaging, CT scans etc. In recent years, the number of publications on applications of AI in radiology is increasing.

Chatbot

One of the most recent AI applications that are gaining recognition is in assisting patients via chatbots. A bot is an AI program that patients can chat with to get assistance with their requests through a window on a website. These bots are expected to be readily available as a feature of services provided by medical organizations.

Data analysis

AI is capable of more than just interpreting human commands and determining the appropriate response. AI has been used in a few specialized applications in oncology, such as identifying abnormalities in X-rays and magnetic resonance (MR) imaging, and in suggesting precise medicines to support personalized treatments for patients (Kim et al., 2017). The IBM Watson AI model was able to process structured and unstructured patient data successfully. In oncology, IBM Watson would provide cancer patients with drug suggestions.

Security and privacy of integrated data

Healthcare AI experts have stated that machines are not always correct and may occasionally fail. Additionally, when AI suggests inappropriate medication or provides misinformation for a patient, these errors will lead to negative consequences; over time, however, once AI has shown its reliability and basis for clinical treatment, it tends to be trusted (Lopes et al., 2021). The stage will be ready for accepting a working scenario in medical treatment if its error margins are less than or nearly identical to human understandings. Patient data required by AI algorithms are stored on the vendor's data servers. This would cause information security and privacy issues if the framework was misused.

Telemedicine

The rise of telemedicine has seen the rise of possible AI applications. AI may enable physicians to truly focus on patients from a distance by tracking their details. A wearable interface could allow an individual to be constantly monitored and physicians to identify changes that are not easily distinguishable by humans (Khvastova et al., 2020). Data from a variety of sources are gathered with caution before using in AI algorithms, so that in the event of a problem, researchers can address it to the best of their abilities.

Drug identification

Medication research databases of pharmaceutical companies can contain a huge amount of data, which average AI algorithms may not be able to handle. A computational model based on the quantitative design action relationship (QSAR) can swiftly predict vast quantities of mixes or fundamental physicochemical attributes such as log P or log D. However, these models are far from anticipating complex organic factors such as drug adequacy and accidental effects (Krittanawong et al., 2019; Kumar et al., 2021). AI can be used successfully in a various fields of drug discovery such as drug design, chemical combination, polypharmacology, drug testing and targeted drugs. Despite the benefits, AI has significant information issues due to its scale, development, variety and uncertainty.

4 Amalgamation of AI and blockchain technology in healthcare

By combining the two revolutionary technologies, AI and blockchain issues can be effectively addressed. AI computations rely on information or data to learn, understand and accomplish their tasks. An AI algorithm functions better when information is obtained from a secure, reliable data repository. Blockchain functions as a distributed record on which information can be stored and transferred in a cryptographically secure way, verified and agreed upon by all mining nodes (Khvastova et al., 2020; Kumar et al., 2021).

Combining AI and blockchain can result in a secure, consistent and decentralized architecture for the sensitive data that AI-driven strategies should gather, store and utilize. This methodology drives key information and data security advancements in various ventures, including clinical, banking, monetary and legal data. With the help of AI integration, blockchain takes care of patient status details with the utmost care to make medical services more effective. This also assists the healthcare organization in developing a framework for synchronizing the actions of patients and service providers (Xue et al., 2017). AI facilitates data identification in a more promising way (Chamola et al., 2022). Apart from imparting knowledge about a patient's lifestyle and health, AI may also help medical researchers with useful findings. Also, when a patient arrives at a clinic with a serious ailment, the computer analyses the situation and recommends treatment options, as well as the length of stay (Khurshid, 2020; Lopes et al., 2021; McKinney et al., 2020).

4.1 Benefits of amalgamation of blockchain with AI

This section shows the benefits of the amalgamation of blockchain with AI technology. Table 7 presents the main general benefits. Benefits for healthcare are explicitly mentioned below this table.

Table 7. *Key benefits of amalgamation of blockchain with AI. See also Table 1.*

Enhanced data security	Blockchain-based data storage is very secure. Blockchains are well-known for securely storing private and sensitive data in a diskless setting. Data in blockchain systems are digitally signed, so only the "respective private keys" need to be kept safe. This enables AI algorithms to operate on secure data, resulting in more trustworthy and reliable decision-making.
Improved trust in robotic decisions	Any choice made by intelligent agents turns defective when clients or people find it difficult to comprehend and rely on. Blockchain is well-known for documenting transactions in decentralised ledgers on a step-by-step basis, making it simpler to accept and trust decisions made, while also ensuring that records are not manipulated during the human-involved auditing. Capturing an AI system's decision-making process on a blockchain would boost openness and trustworthiness in understanding automated decisions. In a swarm robotic ecosystem, where consensus is obtained in a decentralised way, the requirement for a third-party auditor can be eliminated.
Collective decision making	To accomplish the swarm goal in a robotic swarm environment, all intelligent agents must coordinate together. Numerous robotic applications have used distributed and decentralized decision-making algorithms, thus eliminating the need for a centralized authority. Robots vote to make decisions, and the outcomes are decided by majority votes. Every vote cast by each robot is stored on a blockchain as a transaction, and the blockchain is accessible to all robots and can be used to verify voting results. This technique is repeated across all robots until the swarm reaches a decision.
Decentralized intelligence	Various individual data security intelligent agents can be aggregated to provide unified security across the communication layer and to solve scheduling issues when making high-level decisions that involve multiple intelligent agents performing various subtasks which have access to the same training dataset (e.g., scenario of supervised learning).
High efficiency	Usually, business processes involve many stakeholders such as customers, other business and government entities. This leads to multi-party authentication and authorization, which makes the transactions inefficient. The mix of AI and blockchain technologies allows intelligent decentralized autonomous agents (DAOs) to quickly validate transactions automatically across several stakeholders.

Improved decision making

While blockchain can guarantee security and integrity, adding AI capability to the healthcare domain can be helpful. Currently, AI is primarily used to detect abnormalities in X-rays and CT scans, an assignment which AI can accomplish just like a doctor and ensure a higher level of customized treatment to patients. Experts believe that significant innovations will emerge in the future; as a result, there may be huge benefits that may lower clinical expenses and improving the quality of clinical care (Khan et al., 2020a; Kumar et al., 2021). AI should address security and interoperability issues in healthcare.

Large-scale storage of clinical data

Clinical records and other data might be transferred to blockchain-based EHR frameworks. If this information is handled straightforwardly in the blockchain network, the processing overhead will increase because of the small and limited block size. Also, such information will frequently experience the ill effects of a security breach. To overcome these challenges, most fundamental investigations and executions use the structure to oversee massive volumes of secure unique data using distributed computing and blockchain for storage (Vyas et al., 2022).

Data acquisition towards EHR

Patient-generated health data from wearable devices and other electronic equipment might complement traditional data collection. Information gathered by a mobile phone's different sensors (cameras, sound recorders, accelerometers) and wearable devices regularly requires ML handling to infer significant bits of knowledge. The information yielded from these gadgets can be scanty as well as variable in quality and accessibility. The amazing investigation depends on putting out the right data (Khvastova et al., 2020; Lopes et al., 2021). Semantic advancements can be utilized in information securing to extricate related and significant information. This enables the method to locate and eliminate useless data in the information that contains errors or anomalies (Rosebrock, 2020).

4.2 Taxonomy

This section makes a brief discussion on the taxonomy of blockchain with the AI technology for various applications. Figure 5 depicts the various avenues of integrating AI with the blockchain technology.

4.2.1 AI applications with decentralized infrastructure

The conventional blockchains were linear in structure which were based on linked list and hashing techniques. In recent times, to manage big data and real-world applications, a nonlinear structure using graph theory concepts is also emerging.

Linear infrastructure

The linear infrastructure that is used in decentralized applications constitutes of a single chain which scales up slowly and reduces the performance (Salah et al., 2019). Additionally, separate chains are needed for every type of business, which makes the exchange of assets and values impossible across multiple chains. Linear infrastructures, i.e., single chain blockchains are more suitable for tasks such as optimization and autonomous operation.

Nonlinear infrastructure

The nonlinear infrastructure is implemented as multichain blockchains such as parallel chains or child chains (Hwang et al., 2018). In contrast to single chains, multichains are scalable and support variety of business types. The multichain facilitates the transfer of values and asset exchanges between chains. In a multichain setting, one chain that keeps the metadata of all the other chains is called a main chain. The remaining chains are known as child or parallel chains. In the child chain, the business logic is tightly coupled to the main chain and in the parallel chain each chain operates independently. Nonlinear infrastructures are useful for decentralized AI applications which comprise multiple independent or related tasks.

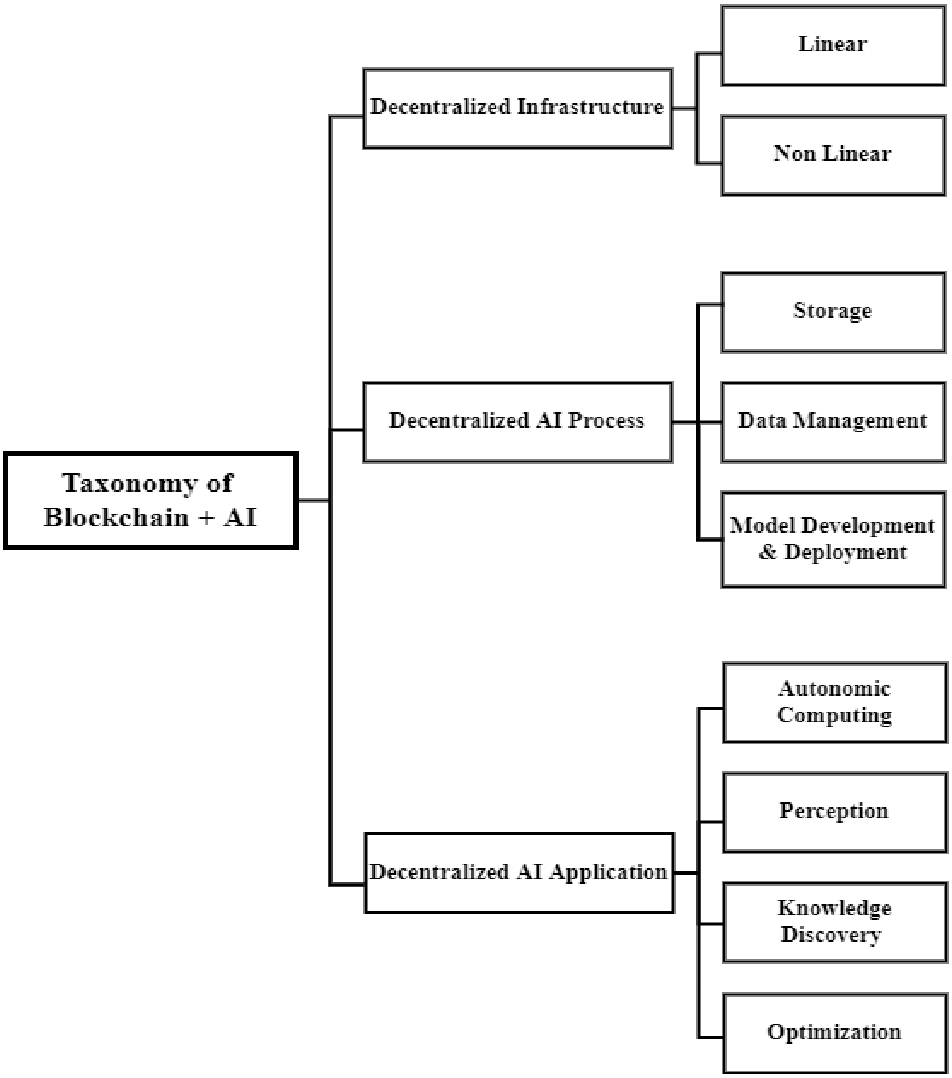

Figure 5. *Taxonomy of blockchain with AI technology.*

4.2.2 Decentralized AI operations

In general, AI applications are capable of handling enormous volumes of data for improvised decision making. Cloud based central storage is used to store large volumes of data, which is the major bottleneck for the development of privacy-preserving and highly secure AI applications.

Decentralized storage

Privacy and security are the major concerns when sensitive data is stored in central data storage (Puneeth and Parthasarathy, 2021). Sensitive data include personal information, EHR, financial data, etc. Decentralized storage, i.e., blockchain-based storage, secures data across networks using cryptographic techniques (Kumar et al., 2021; BigchainDB, 2018). In a decentralized storage architecture, every node maintains a copy of the entire database to guarantee data availability to all users. Some of blockchain-based storage systems are Inter Planetary File System (IPFS), Swarm and Stori.

Data management

Apart from data storage, managing the data is also a critical task for AI-based applications. Relevant data sets which are accurate and complete are collected from reliable sources for AI applications. A minor change in the data will significantly increase the data replication, thus making centralized storage inefficient. It also involves repeated dataset transfers, which increases the network traffic (Vo et al., 2018). Due to this, blockchain-based data management is more suitable for AI applications. To secure and provide integrity of data, only metadata can be stored on the blockchain, and the actual data could be in centralized data storage.

Learning model development and deployment

Learning is a process in AI applications which understands the given dataset and performs decision-making based on the new data. The training approach using centralized storage is costlier because the learning happens from the entire dataset, and this may lead to overfitting as well. The development of a learning model using the decentralized approach is more resource-efficient for the applications (Kurtulmus and Daniel, 2018). After the learning model is efficiently trained, it can be tested using several smart contracts.

The actual performance of the trained model can be evaluated when it is deployed in real time. The deployment of models in centralized data systems is a straightforward process, whereas it is very challenging in decentralized systems (McKinney et al., 2020). Model deployment using smart contracts tackles the challenges. Additionally, models can be shared securely across various applications because the developers can monitor the integrity and version histories of the deployed model (Fatoum et al., 2021).

4.2.3 Decentralized AI applications

AI-based applications can make decisions and operate independently by using several approaches such as searching, knowledge discovery, optimization, etc. Building a decentralized AI applications is a challenging and complex task.

Autonomic computing

To empower partially or completely autonomic operations using several intelligent computer programs is one of the key objectives of AI application (Rizk et al., 2018). For AI applications to work autonomously, huge heterogeneity in various sectors such as data processing, storage systems, data sources, etc., is to be handled by modern computing frameworks. The use of multiagent systems in various sectors does not work with just the managing of heterogeneity, but it additionally helps in setting up the intra and inter layer operability across systems. The blockchain technology can play a key role in decentralizing an autonomous system. It can track and permanently store all the transactions between devices, users, applications, etc.

Perception

The intelligent bots and agents in AI applications and frameworks consistently gather, understand and analyse data from their surroundings using centralized perception techniques, which brings about rigidity in data collection (Fioretto et al., 2018, pp. 623-698). The use of decentralized perception techniques can enable data collection from different perspectives. The advantage of using decentralized perception is that AI systems need not to repeatedly collect data from streams for achieving better quality and successful perceptions. Due to the immutable property of blockchain, only valid perceptions must be saved on the blockchain.

Knowledge discovery and management

Present-day AI applications rely upon large, centralized processing machines for handling massive amounts of data streams. The process of knowledge discovery and management in centralized AI applications benefits in providing system-wide as well as application-wide intelligence but the applications should allow personalized patterns for classes of users, devices, applications, etc. (van Zelst et al., 2018). The decentralized knowledge discovery and management process is envisioned to provide customized patterns based on requirements of all the stakeholders. Additionally, blockchain provides a secure and trackable way of transferring knowledge across various stakeholders in the system.

Optimization

One of the key features of an AI application is to find the best or optimal solutions from all the feasible solutions. Present-day AI systems function in a variety of environments such as resource-constrained, edge computing, cloud computing, etc. Depending upon the system-level and application-level goals, the optimization techniques operate in restricted or unrestricted environments. Present-day optimization techniques implemented in centralized systems with application-wide or system-wide goals often result in reduced application or system performance due to irrelevant and extraneous processing of data (Lu et al., 2017). Decentralization of optimization strategies opens a new area of research opportunities. System performance is increased using decentralized optimization by processing only related data. Decentralized optimization is also useful when several strategies with distinct optimization goals needs to be executed together across systems.

5 Discussion

Recent years have seen fast-paced advancements in digitization of healthcare services, which has resulted in huge amounts of patient data. EHRs are the more feasible option for saving patients' medical information and there is a remarkable vendor potential on the market providing EHR services. EHR services include collecting data online as well as in person and sharing of data with other service providers. The key objective of the EHR is to store and retrieve patient health data securely. EHRs are considered a standard data model which facilitates sharing of data across several healthcare organizations. Although EHRs have several benefits such as improved data management and storage, they have limitations such as security, performance, interoperability, etc. (Reegu et al., 2021; Boumezbeur et al., 2022).

To the best of our knowledge, this is the very first comprehensive review on blockchain and AI-based health record storage. This study has facilitated a thorough review of the integration of blockchain and AI technology in the healthcare domain. According to research questions, we discussed the issues of EHRs, advantages of blockchain and AI in isolation and of their integration. We identified several aspects of studies by answering the research questions. Consequently, we presented a brief taxonomy and identified open issues which can be further investigated.

The key objective of the various studies considered in this article is managing, storing, applying intelligence and securing patient health data. The critical findings presented in this survey show the importance of integrating blockchain with AI applications to overcome the issues faced by these technologies individually in the healthcare sector. Blockchain integrated with AI will soon offer more stable and efficient healthcare solutions (Mamun et al., 2022; Wazid et al., 2020).

Integration of AI and agent-based systems into EHR will enable the process of decision making, coordinating and taking suitable actions. The key aim of this integration is to provide infrastructure, methods and tools for managing EHRs. Besides the challenges in managing critical EHR data, many researchers have focused on ML-based solutions to blockchain-based EHR applications. Blockchain-based AI applications for managing EHR are still in infancy and need to be evaluated in realtime.

5.1 Open research issues

This section discusses the issues and challenges in integrating the AI and blockchain technology.

5.1.1 Security and privacy

Security and privacy are one of the major challenges in blockchain. In a blockchain network, the flow of information is transparent between nodes. The information may consist of private data which users do not wish to disclose. Consequently, safeguarding the privacy of users is critical when blockchain applications are deployed on a large scale. The regular blockchain uses techniques such as identity masking and data hiding for achieving the privacy. Identity masking involves anonymizing user identity and applies group signatures to mask the identity data of both the nodes involved in a transaction. To assure the identity security, administrators can use their private keys to oversee the user information. Information masking techniques such as zero knowledge proof do not disclose any private data present in the transaction.

As a result, the blockchain system is less efficient due to a significant number of computations. Thus, there is a need for improvements in the real-world apps. AI techniques can be utilized to improve the efficiency of blockchain and AI algorithms can be adapted to work in a distributed environment.

5.1.2 Scalability

This issue is one of the critical parameters for the effective implementation of DApps (decentralized applications). If the system is non-scalable, then it cannot be implemented on a larger scale. Scalability includes three parameters which need to be considered: network latency, performance bottleneck and consistency issues. To achieve security in the blockchain, most of the nodes need to reach consensus on the transaction information. The scalability requirement may reduce the consistency, which will make the blockchain diverge. A blockchain network contains several nodes, and the network latency between pair of nodes affects the system scalability. To achieve security and consistency, transactions cannot be executed in parallel, which reduces the transaction throughput.

5.1.3 On-chain and off-chain data cooperation for storage

There are two types of storing the information: traditional storage (off-chain) or on the blockchain (on-chain). Each way of storing data has its own limitations. Traditional storage depends on blockchain to ensure the security and integrity of the data while the blockchain depend on using traditional storage, i.e., off-chain storage to improve the performance. Thus, a right combination of both blockchain and traditional storage is needed. Moreover, the data consistency must be preserved while information is stored on-chain and off-chain. Data are an integral part of AI development. There are several issues pertaining to AI such as poor quality of data, data monopoly, etc. The use of blockchain technology can solve the issues of AI with respect to the data.

5.2 Future work

In this part, we anticipate conceivable exploration work on the convergence of blockchain and AI.

5.2.1 Composite architecture using off-chain and on-chain storage

Considering the various distributed cases, the storage of data and transactions might turn into a composite architecture using both off-chain and on-chain storage. The key advantages of off-chain storage are efficiency, privacy and better economy, but it is challenging for off-chain storage to achieve the blockchain trust. One of the future research directions is to combine off-chain and on-chain storage so that the trust on the chain can be aligned to off-chain storage.

5.2.2 Fairness between security and performance improvements

Although blockchain enjoys many benefits in different perspectives, its own performance bottlenecks restrict its practical usage. Blockchain has several performance issues related to confirmation of transactions, transaction throughput, etc. Block expansion, storing transactions off-chain, DAGs (directed acyclic graphs) are some of the solutions that have been proposed to enhance the efficiency of the blockchain. But these solutions unavoidably diminish the blockchain's reliability and security, although stronger cryptographic algorithms can be used in the blockchain in some applications where privacy is a major concern. However, transaction throughput may be reduced. There must therefore be a proper balance between the privacy and the performance, which needs further research.

5.2.3 Distributed trust formation

In blockchain applications, there is a lot of co-ordination and communication between nodes. The presence of trust among nodes is the basis for their coordination. Trust across nodes in a network is established via a consensus mechanism and the immutable property of the blockchain. In a situation where a node has an identity and a role, the node's identity must be authenticated. This leads to the creation of distributed trust in blockchain. As a part of future work, authenticating the identities of neighbouring nodes in the network without needing a central authority can be researched further.

6 Conclusion

Healthcare experts have access to patients' EHRs stored on the blockchain and AI applications use various algorithms that have a decision-making potential and can handle massive amounts of data. Consequently, integration of the major technologies of blockchain and AI will improve the healthcare domain in terms of performance, security, etc. Blockchain also facilitates the encrypted storing of health records that is required by AI.

In this paper, we presented fundamental information on artificial intelligence and blockchain exhaustively, performed an in-and-out investigation of the possibility of the amalgamation of blockchain and AI, and thoroughly summed up the exploration work on the combination of blockchain and AI on the local market and abroad. We gave an insight into decentralized blockchain storage, which can solve several key issues pertaining to AI. In addition, a brief taxonomy of blockchain and AI was discussed in terms of infrastructure, process and applications. At last, we brought up promising application situations and future work.

The amalgamation of blockchain technology with AI unfolds a new area of research and innovation in the healthcare domain. The advantages of these novel technologies come with real-time challenges, which must be overcome before they can be used in the field of healthcare. Our study shows that the integration of blockchain with AI technology is still in an emerging phase and there are many practical research issues and challenges that need to be addressed, such as scalability, security, privacy, standardization and governance.

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