CSE3013 - Artificial Intelligence
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Blockchain for Biomedical and Healthcare Applications
Article Paper

By:
Mayank Jain - 19BCE0469
Soham Adhikari - 19BCE0816
Vishnu Nair - 19BCE2467

Submitted to:
Professor Jayashree J

Domain:

Bitcoin's creation in 2008 introduced the world to a new concept that is now projected to change society as a whole. It has the potential to impact every industry, including finance, government, media, law, and the arts, to name a few. Some see blockchain as a revolution, while others believe it will be more evolutionary, with any practical benefits taking several years to materialise. To some extent, this idea is correct, but the revolution, in our opinion, has already begun. Many significant companies throughout the globe are already working on blockchain proofs of concept, recognising the technology's disruptive potential. Some firms, on the other hand, are still in the early stages of research, though this is likely to change as the technology advances. It's a technology that has a significant influence on present technologies and has the ability to make a significant difference.

A blockchain is a public digital ledger of transactions that a network of computers keeps safe and hard to hack or modify. Courtesy of the technological advancements, individuals may interact directly with one another without the need for an intermediary such as a government, bank, or other third party.

Cryptography is employed to connect the ever-growing set of records known as blocks. Through peer-to-peer computer networks, each transaction is verified, timestamped, and added to a growing data chain. Once data has been captured, it cannot be modified.

The technology has received the greatest attention as a result of news from the industry and the media about its expansion. The market capitalizations of Ethereum, Bitcoin, Litecoin, Monero and Dash, for example, are all outstanding. Blockchain, on the other hand, isn't only for cryptocurrencies. There are several blockchain-based applications in the commercial and public sectors right now, including crowdfunding, supply chain monitoring, authentication, and voting services, with many more in the works. According to a poll, blockchain is now the most often mentioned technology in financial applications.

How does blockchain work?

Let us look at a more general method of creating blocks. This scheme is presented to provide you a general overview of how blocks are produced and how transactions and blocks are linked:

1. A node initiates a transaction by producing it and digitally signing it with its private key. A blockchain transaction may be used to represent a number of different actions. This is frequently a data structure that represents a value transfer between members in a blockchain network. The transaction data format often includes some value transfer logic, suitable rules, source and destination addresses, and other validation data.
2. The Gossip protocol broadcasts (floods) a transaction to peers, who subsequently validate it according to predetermined criteria. In most circumstances, the transaction must be validated by majority nodes.

3. The transaction is then placed in a block, which is then sent throughout the network once it has been verified. At this moment, the transaction is deemed finished.
4. The freshly created block has now been added to the ledger, and the next block is cryptographically linked to it. This is a link to a hash pointer. The transaction obtains its second confirmation at this point, while the block receives its first.
5. Transactions are reconfirmed every time a new block is produced. Before a transaction on the Bitcoin network is declared complete, it usually requires six validations.

Bitcoin's extraordinarily high volatility and many nations' views about its complexity initially impeded its growth, but the benefits of blockchain, bitcoin's underlying technology, eventually drew global attention. Blockchain's features include a distributed ledger, decentralisation, information transparency, tamper-proof architecture, and openness. The evolution of the blockchain has been slow. Blockchains are now categorised as Blockchain 1.0, 2.0, 3.0, and X.0, depending on their uses.

Blockchain 1.0
This tier was created with the launch of Bitcoin, and it is mostly used for cryptocurrencies. Second, because Bitcoin was the first cryptocurrency, it's only natural to categorise the first generation of blockchain technology as entirely cryptographic currencies. All alternative cryptocurrencies, as well as Bitcoin, are included in this category. It includes important applications such as payments and apps. With the launch of Bitcoin in 2009, this generation began and terminated in early 2010.

Blockchain 2.0
Financial services and smart contracts are among the applications of the second blockchain generation. Futures, options, swaps, and bonds, among other financial assets, are included in this layer. This layer includes applications that go beyond money, finance, and markets. Ethereum, Hyperledger, and other emerging blockchain technologies are part of Blockchain 2.0. This generation began in 2010, when individuals began to consider how blockchain may be used for numerous purposes.

Blockchain 3.0
Other than banking, this third blockchain generation is utilised to construct applications in government, health, journalism, the arts, and justice. This blockchain technology tier includes Ethereum, Hyperledger, and newer blockchains with the capacity to construct smart contracts, as well as Blockchain 2.0. Around the year 2012, multiple applications of blockchain technology in various sectors were investigated, resulting in the formation of this blockchain generation.

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Blockchain X.0
This generation envisions a blockchain singularity in which, similar to the Google search engine, a public blockchain service would one day be open to anybody and everyone. It will provide services to people from all walks of life. It will be a public and open distributed ledger with general-purpose rational agents (Machina economicus) running on it, making choices and interacting with other intelligent autonomous agents on behalf of their owners, and regulated by code rather than legislation or paper contracts. This does not mean that law and contracts will become outdated; rather, law and contracts will be programmable.

Numerous advantages of blockchain technology have been addressed in a variety of sectors and advocated by thought leaders in the blockchain industry from across the world.
Some of the most noteworthy benefits of blockchain technology are as follows:

- **Decentralization:** This is a key principle and advantage of blockchain technology. Validation of transactions does not need the involvement of a trusted third party or intermediary; instead, a consensus mechanism is utilised to agree on the legitimacy of transactions.
- **Transparency and trust:** The system is transparent since blockchains are shared and everyone can see what's on them. As a result, there is an increase in trust. This is especially important in instances when personal discretion in determining recipients is limited, such as the distribution of payments or benefits.
- **Immutability**: Once data has been recorded on the blockchain, changing it is extremely difficult. Although it is not completely immutable, keeping an immutable ledger of transactions is seen as a benefit because changing data is so difficult, if not impossible.
- **Increased Availability:** Because the system is built on thousands of nodes in a peer-to-peer network, and the data is duplicated and updated on each node, it is incredibly dependable.
  The network as a whole continues to function even if certain nodes depart or become unavailable, making it highly available. There is a high level of availability due to the redundancy.
- **Ironclad security:** On a blockchain, all transactions are cryptographically encrypted, ensuring network integrity.

- **Simplification of existing paradigms**: Many businesses, including as banking and health, are now using a disorderly blockchain paradigm. Multiple entities maintain their own databases under this approach, and owing to the different structure of the systems, data exchange might be problematic. However, because a blockchain may act as a single shared ledger for a large number of parties, it can simplify the paradigm by decreasing the burden of administering the several systems that each business maintains.
- **Faster dealings**: The current blockchain approach is unstructured in several areas, including banking and healthcare. In this design, many entities maintain their own databases, and data transfer may be difficult due to the disparate nature of the systems. However, because a blockchain may serve as a single shared ledger for several parties, it has the potential to streamline the process by reducing the administrative burden of each institution's distinct systems.
- **Cost saving**: Because the blockchain idea does not necessitate the use of a trusted third party or clearing house, it can drastically cut overhead costs associated with fees paid to such institutions.

Applications of blockchain

Financial services: In the financial services industry, blockchain technology has already been applied in a number of innovative ways. By providing an automated trade lifecycle in which all parties have access to the same facts about a transaction, blockchain technology simplifies and streamlines the whole asset management and payment process. This eliminates the need for brokers or intermediaries while also assuring transparency and effective data management.

Healthcare industry: Blockchain technology has the potential to revolutionise healthcare data privacy, security, and interoperability. It has the potential to alleviate a number of interoperability difficulties in the industry while also allowing for safe data exchange across the many firms and individuals involved. It removes the requirement for a third party and reduces overhead costs. Encrypting and appending digital signatures to healthcare records may be maintained in distributed databases utilising Blockchains, ensuring privacy and authenticity.

Smart contracts: The notion of "Smart Contracts" is simply generalised from the concept of electronic contracts based on blockchain. The separation of contract signature and execution at the appropriate moment is an important generality. After then, the electronic execution will take place automatically, without the need for human interaction. There are several uses, including the execution of future transactions, such as coupon payment or the expiry of a call or put option, as well as situations of inheritance or goods settlement, or any sort of warrants or authorizations whose execution is deterministic under specific conditions. Such contracts are now signed and guaranteed by notary offices.

Government: The use of blockchain technology in government operations and services has the potential to totally transform them. It has the potential to play a major role in resolving data transactional issues in the government sector, which is currently fragmented. The use of Blockchain for data integration and sharing enables for improved data management across various departments. It improves transparency and makes transaction monitoring and auditing easier.

Travel and Hospitality: Blockchain technology has the potential to transform the travel and hospitality industry dramatically. It may be used to send money, save important documents like as passports and identity cards, make bookings, and manage travel insurance, loyalty, and rewards.

Work Area:

We can see how blockchain is being used and implemented in every major industry across the world. This study, on the other hand, focuses on the healthcare industry in particular and explores the technology's usefulness there.
For increased accuracy and efficacy of medical treatments, the healthcare industry is heading down a road where it will become reliant on massive data sets and distant data pre-processing. This necessitates the integration of Machine Learning Models and AI algorithms into an IoT network in other words, a recipe for generating large amounts of data. When data storage is included in, things start to get interesting. It's not feasible to save all the data in the cloud!
With the advancement of technology, the needs of patients have increased as well. They want their data to be kept private and confidential. However, this demand is a double-edged sword because AI-driven models work on real-time patient data, which is the only way patients can receive appropriate treatment. Unless you combine AI with blockchain technology, keeping this data private would undoubtedly reduce the effectiveness of the treatment.
Only by integrating these technologies can the healthcare sector have the best of both worlds: protecting patients' privacy while also supporting medical research.

The application of artificial intelligence (AI) aids in the discovery of data trends. In addition to enabling more efficient operations and providing insights into the patient's lifestyle and health, AI may assist in the strategic use of analytics. AI is accomplished in two ways: through studying algorithms and by making challenging decisions. When a patient with a life-threatening ailment comes at the hospital, the computer assesses the patient and recommends treatment options as well as length of stay. Then, using Blockchain technology, organisations may identify, verify, and account for the safety and accountability of patient information, giving only authorised access. It also ensures that data is gathered in real time and that it is securely preserved. It also guarantees that data is captured in real time and shared in a similar manner to enhance patient results.

Artificial Intelligence	Blockchain	Integration of AI and Blockchain	Problem it solves
Centralised	Decentralised	Enhanced information security	Allows authorised access of information
Stochastic	Immutable	Making decisions based on evidence	Secure updation of patient records
Volatile	Data integrity	Decentralized intelligence	Usage of data to tailor algorithms
Data, knowledge, and decision-making are all centered on data.	Attack resilient	High efficiency	Accurate generation of results

IoHT (Internet of Healthcare Things), which may be considered as a specialised form of IoT that focuses more on individually identifying equipment in the medical sector, is one of the technologies identified to be effective in this study. Research has been produced that lists many firms in order to shed light on all of the remarkable advancements that have occurred in this industry.

This paper examines current advancements in Blockchain and AI technology, as well as the necessity to integrate them into the healthcare and biomedical industries. After doing comprehensive study, we have determined the short-term goal for this industry: the creation of tamper-proof, pseudo anonymous, secure, reliable, and retrievable patient information. However, this study also discusses several sophisticated uses and breakthroughs, such as drug discovery and accurate genomic data.

Article

1. *Tagde, P., Tagde, S., Bhattacharya, T., Tagde, P., Chopra, H., Akter, R., ... & Rahman, M. (2021). Blockchain and artificial intelligence technology in e-Health. Environmental Science and Pollution Research, 1-22.*

   Technology : EHR systems

   Methodology : Because of the specified and tiny block size, if medical data is handled directly in the blockchain network, the processing overhead and storage pressure will grow. The fact that this data is constantly subject to privacy breaches is a greater worry. As a result, EHR systems transfer medical records and other data to the blockchain.

2. *Farouk, A., Alahmadi, A., Ghose, S., & Mashatan, A. (2020). Blockchain platform for industrial healthcare: Vision and future opportunities. Computer Communications, 154, 223-235.*

   Technology : IoT and IoHT devices

   Methodology: Registrar Contract (RC), Patient–Provider Relationship Contract (PPR), and Summary Contract are the three types of contracts that make up the framework (SC). PPR is produced between two nodes in the system for storing and managing patient medical information, and RC is used to change participant identification to their associated Ethereum address identity. SC is in charge of obtaining patient medical information and displaying all of the participant's prior and current interactions with other nodes in the system. The structure creates a one-of-a-kind framework for maintaining health-information interchange across health-care organisations, institutions, and patients. In addition, the framework includes a universal, secure network architecture, proven identity and authentication of all participants, compatible representation of authority to access electronic health information, and countless other advantages.

Obtained below is a list of firms who are working on blockchain-based healthcare solutions:

Company	Country of origin	Solutions
PokitDok	USA	Identity and claims management for patients, as well as real-time benefits verification (for treatment or pharmacy)
Patientory	USA	Patient healthcare information access management and linking the patient's specialised care team with the community to have a better understanding of the patient's condition
Guardtime	Estonia	Various corporate systems' security and scalability. Estonia's E-government is one of Guardtime's most recent blockchain applications.
Chronicled	USA	The development of a healthcare supply chain with built-in trust, automation, and privacy
Gem	USA	Patient-centered healthcare and tailored treatment are gaining popularity.
Nebula Genomics	USA	Assurance of end-to-end security of the transmission of genomes
Doc.AI	USA	Healthcare data collection and management: Blockchain technology is used to encrypt patient health data, which may then be used in machine learning algorithms to forecast a patient's health state and necessary therapy.
Iryo	Slovenia	The merging of health records from several sources
Coral Health	USA	Create rules that allow patients to communicate their medical information and personal viewpoints with various stakeholders in a secure and efficient manner. The suggested platform allows for a more widespread use of customised medicine.

Medicalchain	Switzerland	Save medical records in a secure manner and share them with various medical stakeholders. Patients' records will only be shared if they have given their permission. Medicalchain's design also includes telemedicine: it allows patients to communicate with their physicians via online chats and distributes their health reports.
EncrypGen	USA	Assist people in safely and reliably exchanging their DNA data for cryptocurrency tokens.
Blockpharma	France	Drug traceability should be improved, and drug copying should be reduced.
BurstIQ, Inc.	USA	AI for data processing and blockchain for data protection are used to unlock the powers of big data.
Shivom	USA	Provide clients with the ability to engage in the Genomic Information Market by assisting with data management regardless of time or location.
Bodyo	UAE	A health pod can be used to measure blood sugar, blood pressure, height, weight, muscle mass, fat mass, and a variety of other parameters.
Exochain	USA	Individuals can choose how clinical trial researchers engage with their medical information. This might lead to an increase in the number and quality of participants recruited for clinical trials, while also providing patients more control over their medical information.
Novartis	Switzerland	False drugs are identified and temperatures are recorded in real time for all stakeholders in the supply chain process using blockchain and IoTs. This ensures that medications are supplied safely.
Curisium	USA	Payers, providers, and life science businesses may all participate in patient-centric value-based

		contracts thanks to secure computation technology.
Healthcombix	USA	New healthcare ecosystems are being built on the backs of confidential human data asset management, illness prediction, and decentralised payment networks.

3. *Wang, K., Dong, J., Wang, Y., & Yin, H. (2019). Securing data with blockchain and AI. Ieee Access, 7, 77981-77989.*

   Technology : Private Data Center (PDC), GAN module (ASC), SGX-based smart contracts

   Methodology:
   Secnet is made up of three key components:
   - Data sharing on the blockchain with ownership assurance;
     SecNet uses HyperNet's Private Data Center (PDC) for data security, which not only offers physical security for data but also universal data access control.Secure computing platform based on AI
   - SecNet has an ASC component in every PDC to safeguard data. ASC combines the Generative Adversarial Network (GAN) module for secure computing at the very starting stage to produce more powerful and dynamic security rules and provide a secure and intelligent OSS for PDC.
   - A system for exchanging trust values in order to purchase security services.SecNet bootstraps advancement of security rules by combining blockchain with SGX-based smart contract execution, allowing well-defined security rules held by one entity to be bought by others in return for value.

4. *Kaldoudi, E., & Drosatos, G. (2019). Blockchain Applications in the Biomedical Domain: A Scoping Review.*

   Technology: Different blockchain-based algorithms

   Results Obtained: Integrity, access control, and integration of health records and associated patient data are all hot topics in research. Other broad and intriguing uses, such as medical research, clinical trials, pharmaceutical supply chain, and medical insurance, are emerging. As of now, blockchain is still searching for its suitable application paradigms, moving away from methods that mention putting real health data chunks in the blockchain and toward solutions that utilise the blockchain as a ledger that stores mostly references to data or data hashes.

5. *Mettler, M. (2016, September). Blockchain technology in healthcare: The revolution starts here. In 2016 IEEE 18th international conference on e-health networking, applications and services (Healthcom) (pp. 1-3). IEEE.*

   Technology : Ethereum Blockchain Network

   Methodology : The Gem Health Network eliminates the restrictions of centralised storage by giving all healthcare practitioners access to the same healthcare information. It's a decentralised network infrastructure built on the Ethereum Blockchain. Medical records and information are presumed to be relevant and transparent, and authorised users are provided real-time access to the most up-to-date treatment information, reducing the risk of medical negligence and preventing health complications caused by misinformation.

6. *Azaria, A., Ekblaw, A., Vieira, T., & Lippman, A. (2016, August). Medrec: Using blockchain for medical data access and permission management. In 2016 2nd international conference on open and big data (OBD) (pp. 25-30). IEEE.*

   Technology : Smart Contracts of Ethereum Blockchain

   Methodology : A registrar contract, summary contract, and patient provider relationship contract comprise the MedRec model, which helps to identify the patient, store the patient's information, and compile any associations the patient may have. There are also provider nodes and patient nodes, both of which are authorised and constructed using Ethereum Blockchain technology and enabled by miners. Overall, the model depicts the advantages of a decentralised database structure, which allows patients and providers to share information without a single point of failure, hence boosting record sharing interoperability. Another advantage of the system is that it handles the issue of data mining incentives, which is a significant issue in the adoption of medical blockchains. Using the system's DNS-like implementation, the system tries to tackle identity management.

7. *Esposito, C., De Santis, A., Tortora, G., Chang, H., & Choo, K. K. R. (2018). Blockchain: A panacea for healthcare cloud-based data security and privacy?. IEEE Cloud Computing, 5(1), 31-37.*

   Technology : EMR (Electronic Medical Record), EHR (Electronic Health Record), PHR (Personal Health Record)

   Methodology : The capacity to generate new EMR instances, store them, and query and retrieve stored EMRs of interest is built into Health Information Systems (HIS). These are then included into graphical user interfaces (GUIs) or Web services. Electronic Health Records (EHRs) are utilised and built in such a way that they allow patient medical history to move with the patient or be made available to numerous healthcare providers to support data exchange or even patient data portability. This also paves the door for a seamless connection with personal health records (PHRs), allowing patients to be more active in data gathering, monitoring of their health status, and so on, using their cellphones or wearable devices. This results in a blockchain-based HIS and a full EMR-EHR-PHR ecosystem.

8. *Zhang, J., Xue, N., & Huang, X. (2016). A secure system for pervasive social network-based healthcare. Ieee Access, 4, 9239-9250.*

   Technology : IEEE 802.15.6 protocol

   Methodology : The PSN system proposes the use of two protocols to assist construct a blockchain-enabled healthcare data system that may transfer data between a patient and their physician via smart devices and sensors. The first protocol is an upgraded version of the IEEE 802.15.6 protocol that manages the presentation of authorised associations for mobile devices and resource-constrained sensor nodes by constructing secure connections with imbalanced computational needs. In the WBAN region, the protocol provides these secure links for sensor nodes and mobile devices. The second protocol employs a blockchain technology to distribute health data across PSN nodes by allowing other PSN nodes to visit each other in the network and get health data using the addresses in the blockchain.

9. *Al Omar, A., Rahman, M. S., Basu, A., & Kiyomoto, S. (2017, December). Medibchain: A blockchain based privacy preserving platform for healthcare data. In International*

conference on security, privacy and anonymity in computation, communication and storage (pp. 534-543). Springer, Cham.

Technology : Elliptic Curve Cryptography (ECC) and smart contracts

Methodology: The patient is the data sender, and they will transmit their personal health information to the system. Because the data sender is so important in data preservation, it is believed that the data supplied to the system is correct. Data encryption takes place at the user's end. After authenticating and gaining access to the system, the data recipient requests the data. An authenticator is a Registration Unit. When a party uses the system for the first time, it saves their ID and PWD to be utilised later. Each party must register just once, and the ID and PWD must be kept safe. Furthermore, customers just need to log in and access their confidential data through a secure route. Unit with Private Access (PAU). After authentication, both parties to the system will be able to communicate with PAU. It requires a secure connection to communicate with the registration unit since PAU will be used to deliver data to the system. It is the system's intermediate unit, via which elements from different levels can communicate with one another.

10. *Dwivedi, A. D., Srivastava, G., Dhar, S., & Singh, R. (2019). A decentralized privacy-preserving healthcare blockchain for IoT. Sensors, 19(2), 326.*

Technology : ARX Encryption Algorithm, Diffie–Hellman Key Exchange protocol

Methodology : Consists of 5 parts - Overlay network, Cloud storage, Healthcare providers, Smart contracts and Patient equipped with healthcare wearable IoT devices. The cloud storage organises user data into identical blocks, each with its own block identifier. These clouds are linked to overlay networks, and the cloud server communicates the hash of the data blocks to the overlay network once the data is saved in a block.
A peer-to-peer network with a dispersed architecture is known as an overlay. A network in this architecture is made up of particular nodes, each of which must establish that they are certified with a valid certificate.
Before creating an account on the network, such a certificate might be uploaded or confirmed. He or she will be able to digitally sign data/transactions across the network once permitted. We arrange the nodes into multiple clusters to maximise network scalability and reduce network latency. Each cluster has a Cluster Head who is in charge of the nodes' public keys. In the event of a delay, every node connected to a cluster can

change the cluster at any moment. The cluster head can also be changed by the nodes belonging to the cluster. The public keys of requesters (healthcare providers) who may access a patient's data, as well as the public keys of requestees (patients) who are authorised to be accessed, are kept by the cluster head.
Insurance companies or patients designate healthcare professionals to perform medical tests or offer medical treatments. After receiving an alert from the network, healthcare service providers deal with patient treatment. They are also handled as network nodes, with permission to receive specific patient data from the cloud. Smart contracts enable the formation of agreements that are implemented when certain circumstances are satisfied in any IoT device. The patient's health data will be collected by the IoT gadget.

11. *Hossein, K. M., Esmaeili, M. E., & Dargahi, T. (2019, May). Blockchain-based privacy-preserving healthcare architecture. In 2019 IEEE Canadian Conference of Electrical and Computer Engineering (CCECE) (pp. 1-4). IEEE.*

Technology: Blockchain, IOT

Methodology: Asymmetric Cryptographic Algorithms (ECC), Blockchain is employed in the proposed architecture to store hashes of users' healthcare data as well as their data access policies. The policies define who has access to the data of the users. The primary modules that make up the system model are as follows:
a) Sensors that are connected to the body of the patient.
b) Smartphone or PDA of the patient (Personal Digital Assistance).
c) An IHM, or a central server that handles and archives the patient's healthcare data (IoT Health Manager).
d) Health-care facilities such as hospitals and clinics.
e) Blockchain network.
f) Miners.

Assume Alice has received from a hospital an ID, a pair of private and public keys, and a HW. She's wearing sensors and using a smartphone (or PDA) to get data from them. The steps below demonstrate how Alice's medical information will be registered and accessible by medical personnel:
a) Alice's smartphone gets data from the sensors in the first phase. PDA categorises them and transmits them to the IHM based on the kind of sensor (such as EEG and ECG).
b) The data is decrypted and stored in a database by Alice's IHM. IHM calculates the hash of the data and uses an asymmetric cryptographic algorithm to encrypt it (e.g. ECC).

The encrypted data is then sent to Alice's specified cluster miner in BC in the form of a transaction. Alice's transaction is received by each minor in the cluster and stored in BC.
c) If a member of the medical staff wants to see Alice's medical records, he must first make a transaction (i.e., request a transaction) that includes Alice's ID. This transaction is transmitted to the cluster that has Alice's information.
d) The miners will examine Alice's data practises. If the asking medical staff's id is found in Alice's rules, the data and its location are encrypted using the medical staff's public key and delivered to the medical staff.
e) Once the medical staff receives the answer to the access transaction, they can access Alice's hash and decrypt it with his private key.
f) Finally, the medical staff sends Alice's IHM a message containing a hash of her data. The message is decrypted and the hash value is obtained by Alice's IHM. If this hash value is legitimate, Alice's data is returned; else, an access forbidden message is returned.

12. *Bhuiyan, M. Z. A., Zaman, A., Wang, T., Wang, G., Tao, H., & Hassan, M. M. (2018, May). Blockchain and big data to transform healthcare. In Proceedings of the International Conference on Data Processing and Applications (pp. 62-68).*

    Technology : Fast Healthcare Interoperability Resources (FHIR), Smart Contracts

    Methodology : Electronic health records are combined with a three-tier system that includes an application layer, a blockchain layer, and an encrypted database layer (EHRs). This becomes an all-encompassing answer that blockchain currently lacks. Because it is already established to enable safe transactions, blockchain is utilised to bring technologies together. Only those with the cryptographic security keys are allowed to access patient information.

13. *Xia, Q. I., Sifah, E. B., Asamoah, K. O., Gao, J., Du, X., & Guizani, M. (2017). MeDShare: Trust-less medical data sharing among cloud service providers via blockchain. IEEE Access, 5, 14757-14767.*

    Technology : Smart Contracts, Access Control Mechanisms

    Methodology : The MeDShare is made up of four levels. The first is a user layer, which includes all of the different types of users that wish to access data from inside the system. The Data Query layer, which comprises sets of querying structures that access, process, forward, or react to queries submitted to the system, is the second layer. The querying system, which is responsible for processing the request, and the trigger, which is responsible for translating actions to and from the smart-contract environment, are then separated into two primary components. The Data Structuring and Provenance layer is the third layer, which consists of individual components that help process requests for data access from the existing database infrastructure through a series of entities, including an authenticator, processing and consensus nodes, smart contracts, smart contract permissioned database, and the blockchain network. The last layer is the Existing Database Infrastructure layer, which is made up of pre-existing database systems that have been deployed by various parties to complete certain functions.

14. *Roehrs, A., Da Costa, C. A., & da Rosa Righi, R. (2017). OmniPHR: A distributed architecture model to integrate personal health records. Journal of biomedical informatics, 71, 70-81.*

    Technology : Chord Algorithm

    Methodology : Through the usage of an application server with specified duties, the model is set up as a P2P (peer to peer) network with a routing overlay. Elasticity and horizontal scalability are among the cloud-related properties. Data sources, a proprietary open standard, middleware, encryption protocol, privacy module, and repositories are some of the components that make up the paradigm. Data sources are input into a proprietary or open standard before being transformed by the middleware. Before being stored in a series of repositories, the data sources are encrypted and validated in a security and privacy module. OmniPHR evaluates the model's performance using laboratory data. OmniPHR also makes advantage of openEHR, an open standard that encourages interoperability by arranging data blocks in a hierarchical manner.

15. *Maslove D, Klein J, Brohman K, Martin P, Using Blockchain Technology to Manage Clinical Trials Data: A Proof-of-Concept Study JMIR Med Inform 2018*

    Technology : Blockchain-based Smart Contracts which are built using the Ethereum platform

    Methodology : The first phases involve the development of metadata, which is then referred to in later reporting stages to guarantee adherence to protocols and predefined analysis. Three major design considerations were considered during our development process:

The first is about the type of blockchain that is most suited for clinical trials applications (public, consortium-based, or private).
The second question is who would use a blockchain-based clinical trials platform.
The final issue is whether the blockchain should contain the research data or just the transaction records.

16. *Tsung-Ting Kuo, Tyler Bath, Shuaicheng Ma, Nicholas Pattengale, Meng Yang, Yang Cao, Corey M. Hudson, Jihoon Kim, Kai Post, Li Xiong, Lucila Ohno-Machado, Benchmarking blockchain-based gene-drug interaction data sharing methods: A case study from the iDASH 2019 secure genome analysis competition blockchain track, International Journal of Medical Informatics,Volume 154,2021.*

    Technology : Blockchain ,smart contract.

    Methodology: Using the Clinical Pharmacogenetics Implementation Consortium (CPIC) resource, we developed gene-drug interaction test datasets. We developed 3 blockchain-based techniques for sharing gene-drug interaction patient records: Query Index, Index Everything, and Dual-Scenario Indexing.

17. *Vazirani A, O'Donoghue O, Brindley D, Meinert E ,Implementing Blockchains for Efficient Health Care: Systematic Review ,J Med Internet Res 2019;21(2):e12439*

    Technology : Blockchain, EHR.

    Methodology: This study focuses on how the decentralized structure of sensitive health information can result in instances when timely information is unavailable, thereby impacting health outcomes. Furthermore, as patient involvement in health care grows, so does the demand for people to have access to and control over their data. Blockchain is a secure, decentralized online ledger that could be used to efficiently manage electronic health records (EHRs), potentially improving health outcomes by offering a conduit for interoperability.

18. *Mamoshina, P., Ojomoko, L., Yanovich, Y., Ostrovski, A., Botezatu, A., Prikhodko, P., Izumchenko, E., Aliper, A., Romantsov, K., Zhebrak, A., Ogu, I. O., & Zhavoronkov, A. (2017). Converging blockchain and next-generation artificial intelligence technologies to*

decentralize and accelerate biomedical research and healthcare. Oncotarget, 9(5), 5665–5690.

Technology : Artificial intelligence, Deep learning, Blockchain, Exonum Framework.

Methodology:
The blockchain is used to create new transaction blocks, store and send keys, and audit itself. Encrypted data is stored in the data storage. Users send and sell data via the marketplace (users), validate data (data validators), purchase personal medical data (customers), and utilize LifePound as a coin (customers) (LifePound users). The system is not completely open, and public instances are utilized in cryptographic proofs for users to ensure the marketplace's correct operation.

19. *Siyal, A. A., Junejo, A. Z., Zawish, M., Ahmed, K., Khalil, A., & Soursou, G. (2019). Applications of Blockchain Technology in Medicine and Healthcare: Challenges and Future Perspectives. Cryptography, 3(1)*

Technology : Blockchain, distributed systems, distributed ledger technology.

Methodology: In this study, we use blockchain as a model to analyze both existing and recent innovations in the field of healthcare. We also address the uses of blockchain, as well as the problems encountered and future prospects.

20. *Hussein AF, ALZubaidi AK, Habash QA, Jaber MM. An Adaptive Biomedical Data Managing Scheme Based on the Blockchain Technique. Applied Sciences. 2019; 9(12):2494.*

Technology : Blockchain, Image Segmentation.

Methodology: Given the dynamic nature of biomedical evidence data and their usage in the sensitive domain of biomedical science, it is important to ensure retrieved data integrity and non-repudiation. In this work, we present a blockchain-based notarization service that uses smart digital contracts to seal a biomedical database query and the respective results. The goal is to ensure that retrieved data cannot be modified after retrieval and that the database cannot validly deny that the particular data has been provided as a result of a specific query. Biomedical evidence data versioning is also sup-ported. The feasibility of the proposed notarization approach is demonstrated using a real blockchain infrastruc-ture and is tested on two different biomedical evidence databases: a publicly available medical risk factor reference repository as well as a secure search function The acquired results, which show a low latency (less than 750 ms) at 400 requests/second, suggests that it could be used in a variety of health care units such as hospitals and clinics.

21. *Athina-Styliani Kleinaki, Petros Mytis-Gkometh, George Drosatos, Pavlos S. Efraimidis, Eleni Kaldoudi, A Blockchain-Based Notarization Service for Biomedical Knowledge Retrieval, Computational and Structural Biotechnology Journal, Volume 16, 2018*

    Technology : Blockchain

    Methodology : Given the dynamic nature of biomedical evidence data and their use in the sensitive sector of biomedical science, it is critical to secure the integrity and non-repudiation of retrieved data. We introduce a blockchain-based notarization service that employs smart digital contracts to seal a biomedical database query and its results. The purpose is to verify that the data cannot be changed after retrieval and that the database cannot legitimately deny that the data was provided as a result of a specific query. Data versioning for biomedical evidence is also supported.The proposed notarization approach's feasibility is proved using a genuine blockchain infrastructure and tested on two major biomedical evidence databases: a medical risk factor reference repository that is open to the public.

22. *Mytis-Gkometh P., Drosatos G., Efraimidis P.S., Kaldoudi E. (2018) Notarization of Knowledge Retrieval from Biomedical Repositories Using Blockchain Technology. In: Maglaveras N., Chouvarda I., de Carvalho P. (eds) Precision Medicine Powered by pHealth and Connected Health. ICBHI 2017. IFMBE Proceedings.*

    Technology : Blockchain, Cryptographic techniques

    Methodology: We describe a blockchain-based notarization service that employs smart digital contracts to certify a biomedical database query and its results. The purpose is to verify that the data cannot be changed after retrieval and that the database cannot legitimately deny that the data was provided as a result of a specific query. Data versioning for biomedical evidence is also supported. The suggested notarization approach is evaluated on two separate biological evidence databases: a freely accessible medical risk factor reference repository, as well as the PubMed databse of biological research references and abstracts

23. *Sharma, A., Bahl, S., Bagha, A.K. et al. Blockchain technology and its applications to combat COVID-19 pandemic. Res. Biomed. Eng. (2020).*

    Technology : Blockchain.

    Methodology: We suggest a blockchain-based framework to address the current pandemic in this article. Furthermore, we identified and explored nine significant blockchain applications in addressing the COVID-19 pandemic challenge. The most recent information about blockchain and its application in overcoming difficult difficulties caused by the COVID-19 epidemic is gathered and discussed from the available literature found on PubMed, Scopus, and Google scholar.

24. *Prateek Pandey & Ratnesh Litoriya (2020) Securing and authenticating healthcare records through blockchain technology, Cryptologia, 44:4, 341-356,*

    Technology: Blockchain, cryptography.

    Methodology: A decentralized system is computationally expensive, but it has the potential to be revolutionary by keeping the patient at the center and offering security, transparency, privacy, and interoperability of electronic healthcare data. A blockchain is an implementation of a distributed and decentralized system that employs dependable cryptography techniques. This study presents a secure blockchain-based architecture adapted specifically to the needs of e-healthcare systems.

25. *Liu, H., Crespo, R. G., & Martínez, O. S. (2020). Enhancing Privacy and Data Security across Healthcare Applications Using Blockchain and Distributed Ledger Concepts. Healthcare, 8(3), 243.*

    Technology: Cyber security and blockchain.

    Methodology: Blockchain and Distributed Ledger-based Improved Biomedical Security systems (BDL-IBS) are presented in this articstudyle to improve privacy and data security across healthcare applications. Furthermore, we want to make it possible for patients to use data to support their care and to provide strong consent systems for sharing data among different organizations and applications, because this involves managing and accessing a large amount of medical information, and this technology can keep data reliable.

26. *A. D. Dwivedi, L. Malina, P. Dzurenda and G. Srivastava, "Optimized Blockchain Model for Internet of Things based Healthcare Applications," 2019 42nd International Conference on Telecommunications and Signal Processing (TSP), 2019, pp.*

    Technology: IOT, Blockchain

    Methodology: In this paper, we take a first look at implementing the core elements of Blockchain to a health application network, where patients' health data may be used to provide vital alerts for authorized healthcare practitioners in a secure and private manner. This paper also discusses the advantages and disadvantages of blockchain-based security measures in IoT.

27. *X. Liang, J. Zhao, S. Shetty, J. Liu and D. Li, "Integrating blockchain for data sharing and collaboration in mobile healthcare applications," 2017 IEEE 28th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC), 2017, pp. 1-5.*

    Technology: Blockchain, wearable devices.

    Methodology: We present an innovative user-centric health data sharing solution based on a decentralized and permissioned blockchain that protects privacy through a channel formation scheme and improves identity management through the blockchain's membership service. A mobile application is used to collect health data from personal wearable devices, manual input, and medical devices, and then synchronize the data to the cloud for sharing with healthcare professionals and health insurance companies. To ensure the integrity of health data, a proof of integrity and validation is permanently retrievable from a cloud database and is anchored to the blockchain network within each record. Furthermore, to handle massive data sets of personal health data collected and uploaded via the mobile platform, we use a tree-based data processing and batching technique for scalability and performance considerations.

28. *Sammeta, N., Parthiban, L. Hyperledger blockchain enabled secure medical record management with deep learning-based diagnosis model. Complex Intell. Syst. (2021).*

Technology: Blockchain, deep-learning principles

Methodology: This study proposes a novel hyperledger blockchain-enabled secure medical data management (HBESDM-DLD) model with deep learning (DL)-based diagnosis. Encryption, optimal key generation, hyperledger blockchain-based safe data management, and diagnosis are all part of the model provided. The model provided allows the user to restrict data access, allow hospital authorities to read/write data, and notify emergency contacts. SIMON block cipher technology is used for encryption. Simultaneously, to improve the efficiency of the SIMON approach, a group teaching optimization algorithm (GTOA) is used for optimal SIMON key generation.Furthermore, medical data is shared utilizing a multi-channel hyperledger blockchain, which uses a blockchain for storing patient visit data and for medical institutions to record links to EHRs stored in external databases. Once the data has been encrypted at the receiving end, a variational autoencoder (VAE)-based diagnostic model is used to detect the presence of illnesses. The HBESDM-DLD model's performance is validated using a benchmark medical dataset, and the results are examined using multiple performance measures.

29. *Maslove DM, Klein J, Brohman K, Martin P,Using Blockchain Technology to Manage Clinical Trials Data: A Proof-of-Concept Study,JMIR Med Inform 2018;6(4):e11949*

Technology: Ethereum

Methodology: The paper proposes BlockTrial, an implementation that uses smart contracts on the Ethereum network to manage clinical trial data, ensuring automation of the execution of specific operations when the parties involved are intimate. Researchers can use a web interface to submit queries for data that is stored off-chain. Patients have the option of granting specific researchers access to their clinical data. Using a distributed ledger, researchers and patients can obtain a trustworthy and tamper-proof log of the data.

30. *Wong, D.R., Bhattacharya, S. & Butte, A.J. Prototype of running clinical trials in an untrustworthy environment using blockchain. Nat Commun 10, 917 (2019).*

Technology: any blockchain

Methodology: An untrustworthy environment like the current clinical trial process is vulnerable to anthropogenic errors, malicious or unintentional. A blockchain as a data structure ensures safeguarding of the transmission of large volumes of confidential clinical data due to its immutable nature and sensitivity to tamper. The proposed methodology also promises a useful audit trail for trial regulators as the blockchain technology is well known for its application as a distributed ledger to handle and store sensitive data.

31. *F. Angeletti, I. Chatzigiannakis and A. Vitaletti, "The role of blockchain and IoT in recruiting participants for digital clinical trials," 2017 25th International Conference on Software, Telecommunications and Computer Networks (SoftCOM), 2017, pp. 1-5*

Technology: any blockchain

Methodology: The paper proposes a privacy-preserving architecture of flow of personally identifiable information of individuals who are to be recruited for clinical trials according to trial-specific requirements, based on the blockchain principle. A gateway regularly communicates data from an individual's personal space (wearables and other IoMT devices) which is used by the Clinical Research Institute to enroll the person for an actual trial without the data being associated with the person till after their consent, while maintaining integrity of the historic dataset that the individual has contributed to.

32. *Park YR, Lee E, Na W, Park S, Lee Y, Lee J "Is Blockchain Technology Suitable for Managing Personal Health Records?" Mixed-Methods Study to Test Feasibility J Med Internet Res 2019;21(2):e12533*

Technology: Ethereum 1.8.4

Methodology: Uses Ethereum 1.8.4 to construct a private blockchain upon which a verification process was conducted with the de-identified public health records of 300 patients. The blockchain, which consisted of one hospital node and 300 patient nodes, was used to propagate this data and analyse the time and energy required to do so. For reproducibility this was iterated a 100 times.

33. *Das, Ashok Kumar, Basudeb Bera, and Debasis Giri. "AI and Blockchain-Based Cloud-Assisted Secure Vaccine Distribution and Tracking in IoMT-Enabled COVID-19 Environment." IEEE Internet of Things Magazine 4.2 (2021): 26-32.*

    Technology: any blockchain network and cloud-based big data analytics platform

    Methodology: If transactions relevant to vaccine orders, distribution and tracking are put into blocks, the security of the COVID-19 supply chain which facilitates access to PPE, diagnostic supplies, biomedical equipment and vaccines, will be enhanced, due to its transparency, decentralisation and immutability. This robust security framework also allows big data analytics onto the data in the blockchain with support from IoMT based cloud computing practices.

34. *Liu, W., et al. "Advanced block-chain architecture for e-health systems." 2017 IEEE 19th International Conference on e-Health Networking, Applications and Services (Healthcom). IEEE, 2017.*

    Technology: any blockchain

    Methodology: If medical records are exchanged at the personnel-level via a distributed architecture such as the blockchain, it will greatly increase agility and reduce overheads introduced by intermediaries, while democratizing the exchange of medical records reliably.

35. *Bocek, Thomas, et al. "Blockchains everywhere-a use-case of blockchains in the pharma supply-chain." 2017 IFIP/IEEE symposium on integrated network and service management (IM). IEEE, 2017.*

    Technology: modum.io

    Methodology: The medical industry has many complex and strict environmental control processes (e.g., temperature and humidity) to ensure quality control and regulatory compliance over the transport of medical products. If the pertinent sensors are connected via an IoT framework and integrated with blockchain, GDP compliance can be ensured systematically. All sensor data is uploaded to the blockchain where a smart contract assesses it against product attributes, also stored in the blockchain, minimizing human involvement and database maintenance.

36. *Kamel Boulos, Maged N., James T. Wilson, and Kevin A. Clauson. "Geospatial blockchain: promises, challenges, and scenarios in health and healthcare." (2018): 1-10.*

Technology: Geospatial blockchain

Methodology: Existing geo-spatial blockchain solutions employ a crypto spatial coordinate system to add an immutable spatial context. Multiple applications in healthcare are possible, ranging from patient and provider identification with geotagged data, monetization of this data, validating, crediting and rewarding crowd sourced data to medical fraud detection and public health surveillance using IoMT devices integrated with geospatial blockchain to map real world events to their exact spatiotemporal coordinates.

37. *Hathaliya, Jigna, et al. "Blockchain-based remote patient monitoring in healthcare 4.0." 2019 IEEE 9th International Conference on Advanced Computing (IACC). IEEE, 2019.*

Technology: IoMT and blockchain

Methodology: A network of wearable sensors can suffice for a Remote Patient Monitoring (RPM) based on IoMT which can allow physicians to get real time patient data for efficient diagnosis. Such sensitive data can be secured and its privacy can be enhanced by the Permissioned blockchain based healthcare architecture proposed in this paper.

38. *Mashamba-Thompson, Tivani P., and Ellen Debra Crayton. "Blockchain and artificial intelligence technology for novel coronavirus disease 2019 self-testing." (2020): 198.*

Technology: AI and blockchain couple

Methodology: A self testing and tracking system to curtail COVID-19 transmission based on blockchain coupled with artificial intelligence can prevail against shortcomings like overburdened healthcare system and poor surveillance system typical in high income countries and limited laboratory infrastructures.

39. *Bhattacharya, Pronaya, et al. "Bindaas: Blockchain-based deep-learning as-a-service in healthcare 4.0 applications." IEEE Transactions on Network Science and Engineering (2019).*

    Technology: Deep learning and blockchain

    Methodology: Blockchain based Deep learning As A Service (BinDAAS) which integrates blockchain technologies with deep learning techniques to share and analyse Electronic Health Record (EHR) operates in two phases- in the first, an authentication and signature scheme is proposed based on lattice cryptography to resist collusion attacks, and in the second phase where Deep Learning is applied to patient records to predict future diseases and gain insight into current indicators. This can replace cloud-based architectures proposed which are prone to malicious attacks, trust management and non-repudiation issues among servers. The results obtained from an implementation of the proposed service has been used for comparison based on mining time, accuracy, end to end latency and computation and communication costs, with existing state-of-the-art proposals.

40. *Roman-Belmonte, Juan M., Hortensia De la Corte-Rodriguez, and E. Carlos Rodriguez-Merchan. "How blockchain technology can change medicine." Postgraduate medicine 130.4 (2018): 420-427.*

    Technology: blockchain

    Methodology: introspects the scope of Blockchain Technology (BCT) in the healthcare sector and discusses various applications in legal medicine, electronic medical records (EMR), big data analysis on medical data, teaching and payment regulation for medical services that could change the paradigm of current medicine. Since BCT is open-source, its implementation and management can be democratized among everyone involved in the healthcare sector, while being decentralised.

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