



Blockchain Brains: Pioneering AI, ML, and DLT Solutions for Healthcare and Psychology

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Abstract

In an era marked by rapid technological advancement, the fusion of Artificial Intelligence (AI), Machine Learning (ML), and Distributed Ledger Technology (DLT), commonly referred to as blockchain, represents a pioneering frontier in healthcare and psychology. This paper explores the transformative potential of integrating these technologies to reimagine traditional practices and unlock novel approaches to patient care, diagnostics, therapy, and mental health management. Specifically, it investigates the unique and complementary roles that AI, ML, and DLT can play within healthcare and psychology, presenting a detailed roadmap for researchers, practitioners, and stakeholders. Through AI and ML's advanced analytics and predictive capabilities, and blockchain's secure, decentralized data management, this paper demonstrates how these technologies can collectively enhance diagnostic precision, personalize treatment plans, optimize resource allocation, and streamline administrative workflows. Central to this study is a proposed technical architecture, illustrating how AI, ML, and DLT can be integrated within healthcare workflows. This includes using blockchain for secure, verifiable patient data storage and off-chain AI/ML processing for real-time, data-driven insights. Additionally, this paper discusses practical methods, such as zero-knowledge proofs and federated learning, to maintain privacy and regulatory compliance in handling sensitive health data, especially in mental health contexts. Addressing the importance of ethical considerations, this paper highlights best practices in responsible innovation, emphasizing transparency, accountability, and fairness in the deployment of these technologies. Compliance with frameworks like GDPR and HIPAA is discussed as crucial for ensuring patient rights and establishing trust in data handling practices. Moreover, the paper underscores the need for interdisciplinary collaboration, identifying structured models for joint efforts between healthcare professionals, data scientists, and blockchain developers. Examples include cross-disciplinary training sessions, shared project management

frameworks, and collaborative validation processes that ensure AI models align with clinical relevance and ethical standards. Recognizing the dynamic landscape of AI-ML-DLT convergence, this paper also outlines future research directions, including addressing challenges in scalability, interoperability, and explainability, which are pivotal for the responsible evolution of these technologies. By pioneering AI, ML, and DLT solutions specifically tailored for healthcare and psychology, this paper aims to catalyze transformative change, foster interdisciplinary collaboration, and enhance the quality, accessibility, and affordability of healthcare services. In advancing our understanding and treatment of mental health disorders, this research strives to set a foundation for ethical, effective, and equitable technological integration in healthcare, contributing to improved patient outcomes and societal well-being.

Subject Areas

Artificial Intelligence (AI) and Machine Learning (ML) in Healthcare and Psychology, Distributed Ledger Technology (DLT) in Healthcare and Psychology, Data Security, Privacy, and Ethical Compliance

Keywords

Artificial Intelligence (AI), Machine Learning (ML), Distributed Ledger Technology (DLT), Data Security and Privacy, Personalized Treatment, Interdisciplinary Collaboration, Healthcare

1. Introduction

In the contemporary landscape of technological innovation, the convergence of Artificial Intelligence (AI), Machine Learning (ML), and Distributed Ledger Technology (DLT) heralds a new frontier of possibility and transformation, particularly within the realms of healthcare and psychology [1]. This introduction serves as a gateway to understanding the symbiotic relationship between these cutting-edge technologies, elucidating their individual facets and collective potential within these critical fields. Artificial Intelligence encompasses a diverse array of techniques aimed at imbuing machines with human-like cognitive abilities, with applications ranging from natural language processing to computer vision [2]. Within healthcare and psychology, AI facilitates advanced diagnostics, personalized treatment plans, and predictive analytics, revolutionizing patient care and therapeutic interventions. Machine Learning, as a subset of AI, empowers systems to learn and adapt from data without explicit programming, catalyzing advancements in predictive modelling and decision-making processes [3]. In healthcare and psychology, ML algorithms analyze vast datasets to identify patterns, predict patient outcomes, and optimize treatment strategies, enhancing the efficacy and efficiency of clinical practices. Meanwhile, Distributed Ledger Technology, epitomized by blockchain, introduces a change in basic assumptions in data management and transactional integrity [4]. By decentralizing control and

ensuring transparency and immutability, DLT instills trust in healthcare and psychological interventions, safeguarding sensitive patient information and facilitating secure peer-to-peer interactions [5]. In an era defined by rapid technological evolution, the significance of synergy cannot be overstated. The convergence of AI, ML, and DLT within healthcare and psychology transcends the sum of their individual parts, unlocking unprecedented capabilities and driving exponential progress [6]. By integrating complementary technologies, we can surmount complex challenges, optimize processes, and cultivate transformative solutions with far-reaching implications for patient care, mental health management, and clinical research [7]. The motivation to explore the intersection of AI, ML, and DLT within healthcare and psychology stems from a collective aspiration to harness the full spectrum of technological prowess for societal benefit [8]. This convergence holds immense promise in revolutionizing diagnostics, treatment modalities, and therapeutic interventions, improving patient outcomes and advancing our understanding of mental health disorders. As we embark on this journey of exploration and discovery, this paper endeavors to unravel the intricacies of AI-ML-DLT convergence within healthcare and psychology, offering insights, strategies, and frameworks to navigate this dynamic landscape effectively. Through collaborative efforts and interdisciplinary synergy, we stand poised to unlock the boundless potential of blockchain brains, ushering in a new era of technological enlightenment and societal advancement in these critical domains.

2. State-of-the-Art

The current landscape of Artificial Intelligence (AI), Machine Learning (ML), and Distributed Ledger Technology (DLT) is characterized by a convergence of groundbreaking advancements and widespread adoption across industries, particularly within the domains of healthcare and psychology [9]. In AI, recent research endeavors are homing in on augmenting model robustness, interpretability, and generalization capabilities, amplifying their utility in healthcare diagnostics, treatment planning, and psychological profiling. Breakthroughs in deep learning architectures, natural language processing, and computer vision are catalyzing personalized healthcare interventions and advancements in mental health assessment [10]. Meanwhile, ML continues to push the boundaries of possibility, with innovations in algorithmic scalability, model interpretability, and the democratization of ML tools and techniques. This democratization empowers healthcare practitioners and psychologists to harness the power of data-driven insights, fueling advancements in patient care, treatment efficacy, and psychological interventions. DLT, notably exemplified by blockchain technology, has emerged as a transformative solution for decentralized and transparent record-keeping within healthcare and psychological practice [11]. Blockchain implementations ensure secure and immutable transactional solutions, enhancing patient data management, preserving confidentiality, and fostering trust in therapeutic interactions [12]. From personalized treatment plans to secure patient data management and transparent therapy sessions, the integration of AI, ML, and DLT is revolu-

tionizing traditional processes and reshaping the landscape of healthcare and psychology [13]. As these technologies continue to evolve and intersect, they hold immense potential to drive unprecedented levels of efficiency, transparency, and innovation across the global healthcare ecosystem. By harnessing the synergies between AI, ML, and DLT, stakeholders within healthcare and psychology can unlock new opportunities, address complex challenges, and shape a future defined by improved patient outcomes, enhanced mental health care, and greater societal well-being.

3. Fundamentals

This section serves as a cornerstone, offering a detailed exploration of the foundational principles underpinning Artificial Intelligence (AI), Machine Learning (ML), and Distributed Ledger Technology (DLT) within the context of healthcare and psychology. Understanding these fundamental principles is essential for comprehending the nuances of their convergence and synergies, which are pivotal for driving innovation and transformative solutions in these critical situations.

3.1. In-Depth Explanation of AI Concepts

Artificial Intelligence (AI) represents the pinnacle of human endeavor to imbue machines with cognitive capabilities akin to human intelligence [14]. Rooted in various disciplines such as computer science, mathematics, and cognitive psychology, AI encompasses a rich tapestry of theories, methodologies, and applications. AI allows computers to accomplish things that are simple for humans to do but complex to express explicitly [15]. Such jobs are frequently performed in complicated or unpredictable contexts. Despite ongoing societal debates about Artificial General Intelligence, which refers to computer programs that can control themselves and solve tasks in a variety of domains, most deployed AI-based systems solve tasks in narrow application domains and are referred to as Narrow AI [16]. There are several techniques for designing such restricted AI-based systems. For example, knowledge bases have received a lot of attention from researchers in the past. Nowadays, Machine Learning (ML) appears to be the most widely used technique to develop AI-based systems. ML-based systems are built around a model that depicts a function between input and output data. In most circumstances, machine learning models must be trained. During this training phase, an optimization algorithm adjusts the model parameters to reduce a loss or maximize a reward [17]. Training options vary depending on the application. In the case of supervised machine learning, the input data and output data are known during the training stage.

In unsupervised machine learning, just the input data is known; there is no output data [18]. In a reinforcement learning context, a learning agent performs behaviors that result in an immediate reward, but the agent's purpose is to maximize a future, cumulative benefit. In general, the training step might demand a considerable quantity of data and hence be computationally intensive [19]. This is

especially true for deep neural networks, which are complicated ML models with several parameters that have paved the way for many recent advances in machine learning. In **Figure 1**, we provide a high-level overview of several ways to create AI-based systems.

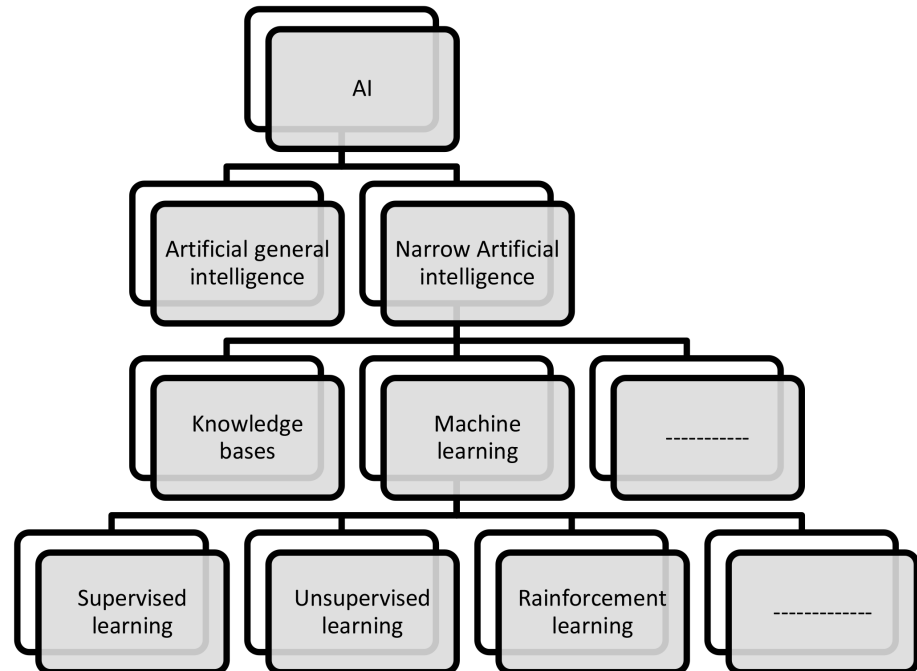


Figure 1. Overview of artificial intelligence.

3.2. Understanding the Fundamentals of DLT and Blockchain

DLT allows for the operation of a universally available, append-only, peer-to-peer database in untrustworthy contexts defined by Byzantine failures, with independent storage devices maintaining a local replication of the data stored on the ledger [20]. A distributed ledger can be deployed as a public ledger, which allows a new node to join a new network immediately, or as a private ledger, which requires permission to join the network. Another feature that distinguishes distributed ledgers are the write permissions: In the case of permissionless ledgers, each node has equal write access. In the case of permissioned ledgers, nodes must be granted permission before validating and committing new data [21].

Figure 2 shows an overview of DLT ideas with various properties. DLT, particularly blockchain, is now being used for applications beyond financial transactions, such as medical data management, autonomous driving, and decentralized gaming. Distributed Ledger Technology (DLT), epitomized by blockchain, represents a change in basic assumptions in data management, transactional integrity, and decentralized consensus [22]. At its core, DLT is a distributed database that maintains a continuously growing list of records, or blocks, linked together and secured through cryptographic hashes, ensuring immutability, transparency, and decentralization.

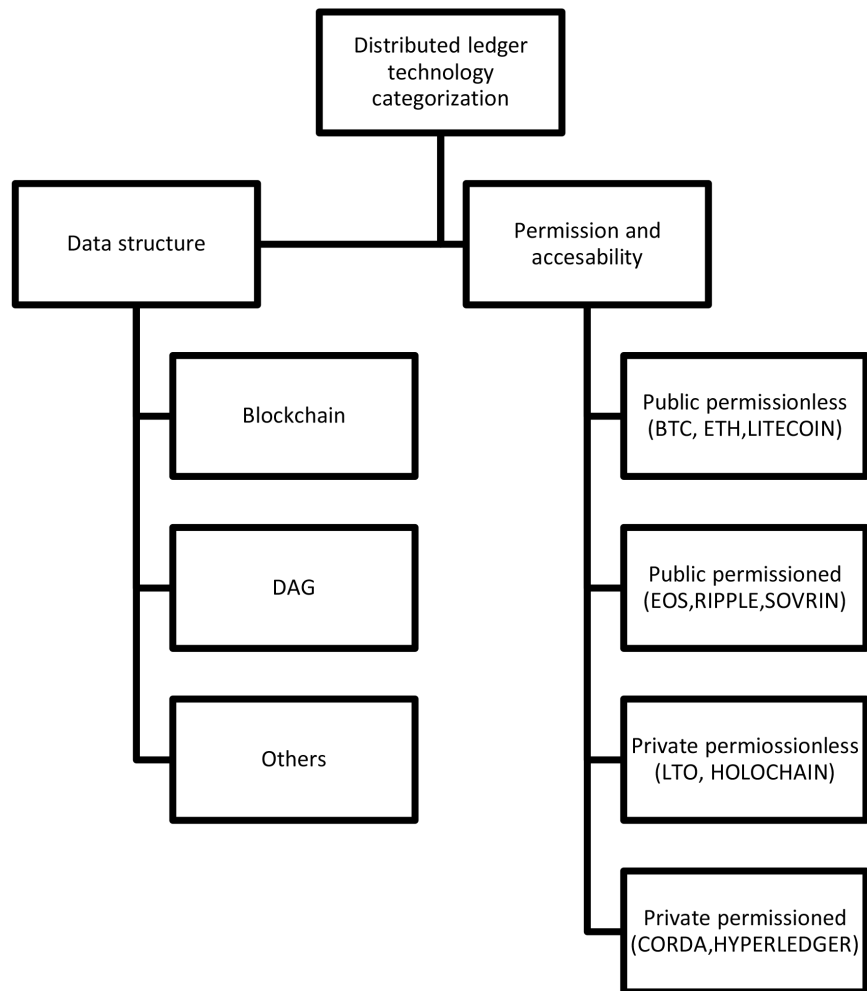


Figure 2. Categories of distributed ledger technologies.

The fundamentals of DLT and blockchain encompass a myriad of concepts and mechanisms, each contributing to its robustness and resilience. Consensus mechanisms, such as Proof of Work (PoW) and Proof of Stake (PoS), govern the process by which transactions are validated and added to the blockchain, ensuring agreement and consistency across network participants [23]. Cryptographic protocols, including public-key cryptography and hash functions, underpin the security and integrity of blockchain networks, enabling secure transactions, identity verification, and data immutability [24]. Smart contracts, self-executing contracts with predefined rules and conditions encoded within the blockchain, automate, and enforce contractual agreements, facilitating trustless interactions and reducing the need for intermediaries. Understanding the fundamentals of DLT and blockchain entails delving into the intricacies of decentralization, consensus, cryptography, and smart contract execution. As blockchain continues to disrupt traditional industries and reshape economic and social systems, a nuanced understanding of its underlying principles is essential for navigating its complexities and harnessing its transformative potential [25]. The fundamentals of AI, ML, and

DLT serve as the bedrock upon which their convergence and synergies are built [26]. A deep understanding of these foundational principles is indispensable for navigating the complexities of AI-ML-DLT integration, unlocking new possibilities, and driving innovation across diverse domains.

4. Challenges and Opportunities in Integrating AI, ML, and DLT

Integrating Artificial Intelligence (AI), Machine Learning (ML), and Distributed Ledger Technology (DLT) within healthcare and psychology introduces both challenges and opportunities [27]. Technical complexities stem from the differing nature of these technologies, which require intricate integration to achieve seamless functionality across systems. A primary challenge is technical data security and privacy, particularly in decentralized environments where robust measures are critical to protect sensitive patient information, especially in mental health applications [28]. Given the sensitivity of psychological data, the Privacy Protection in Mental Health Data subsection is essential, focusing on the legal frameworks and practical methods to protect privacy [29]. Techniques such as zero-knowledge proofs and advanced encryption can enable secure data verification without exposing personal details, thus aligning with regulatory requirements like GDPR in Europe and HIPAA in the United States [30].

Additionally, interoperability challenges complicate integration efforts, requiring the harmonization of diverse systems and standardized protocols for data exchange. Algorithmic bias and fairness also present ethical considerations, necessitating thorough scrutiny and mitigation strategies to ensure AI and ML systems deliver equitable outcomes in healthcare and psychology [31]. Addressing these ethical concerns is vital to upholding patient rights and fostering unbiased healthcare practices. Despite these challenges, the convergence of AI, ML, and DLT unlocks numerous opportunities for innovation. Integrating these technologies enables advancements in diagnostics, personalized treatment plans, and predictive modelling, improving patient outcomes and streamlining healthcare delivery processes. DLT, specifically blockchain, offers a robust solution for healthcare applications, providing security, integrity, and interoperability of medical data. Blockchain's decentralized nature supports privacy and real-time accessibility of patient records, enhancing trust in data handling practices [32]. However, deploying blockchain in healthcare still faces limitations and requires careful research to ensure scalability and compliance with privacy standards.

In this framework of **Figure 3**, ethical data management becomes crucial. Legal and ethical compliance, particularly for sensitive mental health data, ensures that patient information is managed responsibly and that data-sharing practices align with established regulatory guidelines. Through continuous efforts to address these challenges and leverage technological opportunities, stakeholders can enable AI-ML-DLT integration that respects patient privacy, advances healthcare outcomes, and upholds the ethical standards essential for sensitive psychological care.

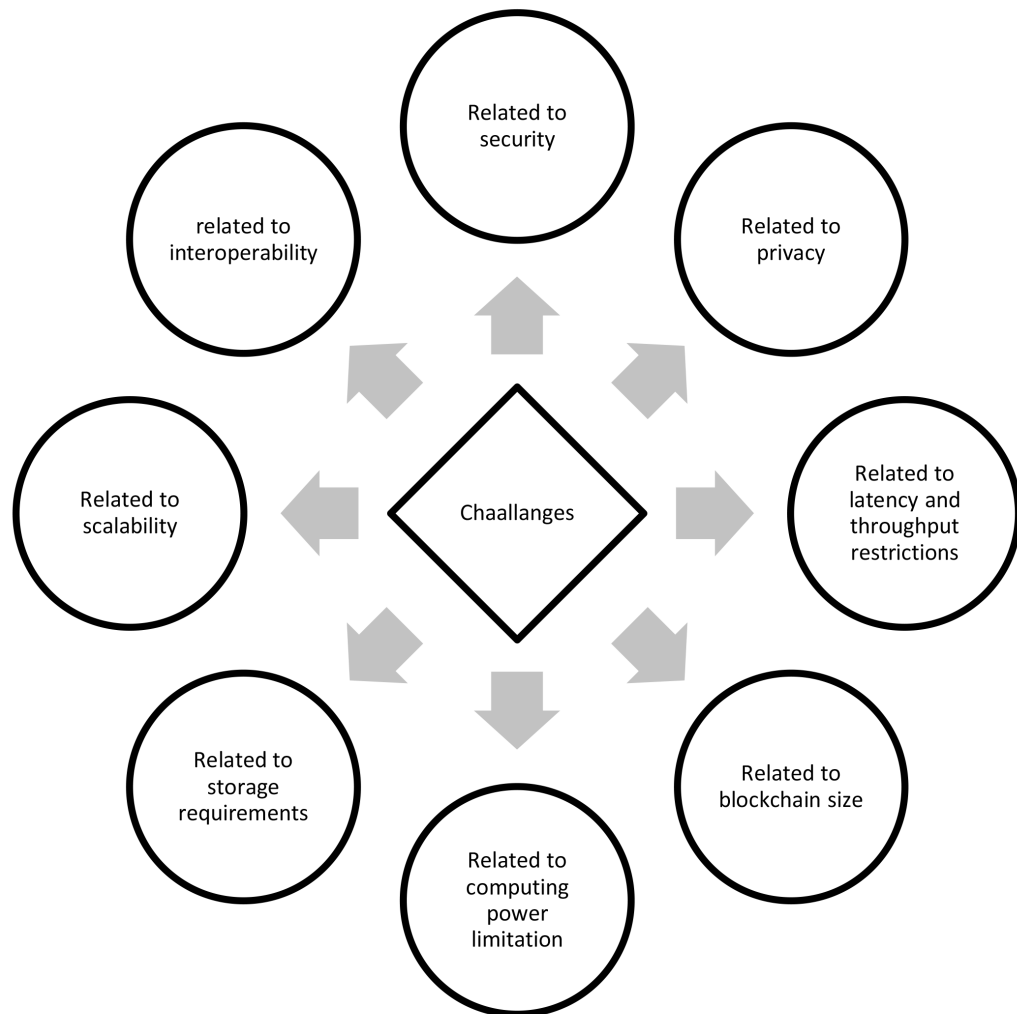


Figure 3. Challenge categories in using blockchain technology in healthcare applications.

In psychology, AI-driven tools augment assessments, therapy interventions, and mental health monitoring, offering tailored support to individuals [33]. Blockchain-powered data security ensures the integrity and confidentiality of patient records, fostering trust and transparency in healthcare and psychological practice [34]. Interdisciplinary collaboration among AI experts, ML researchers, psychologists, and healthcare professionals fuels the development of innovative solutions tailored to address complex challenges. Moreover, addressing regulatory compliance and ethical considerations is paramount. Compliance with data protection regulations, ethical use of AI and ML, and transparency in algorithmic decision-making are essential to uphold patient rights and ensure responsible deployment of these technologies [35]. Continuous monitoring and evaluation enable stakeholders to assess impact, identify risks, and refine solutions, ensuring efficacy and safety in transforming healthcare and psychological practice. Through concerted efforts to address challenges and leverage opportunities for collaboration, stakeholders can navigate regulatory and ethical considerations to harness

the full potential of AI, ML, and DLT in advancing patient care and psychological well-being.

5. Exploration of Real-World Use Cases Leveraging AI, ML, and DLT in Healthcare and Psychology

In the realm of healthcare, the integration of blockchain technology alongside AI and ML has yielded transformative use cases, revolutionizing patient care, data management, and treatment outcomes [36]. One notable application lies in medical records management, where blockchain ensures the secure and immutable storage of patient data, enhancing confidentiality and accessibility for healthcare providers. By leveraging AI and ML algorithms, healthcare professionals can analyze vast datasets to derive actionable insights for personalized treatment plans, disease prediction, and early intervention strategies [37]. For instance, AI-powered diagnostic tools can accurately detect abnormalities in medical images, aiding in the early detection of diseases such as cancer.

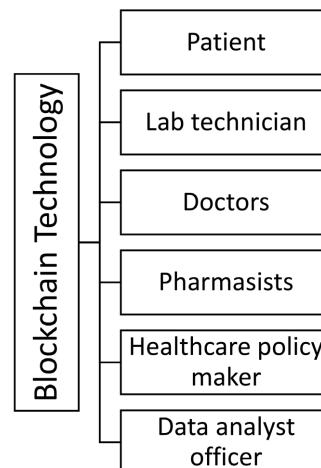


Figure 4. Sharing health information using BCT.

Moreover, as illustrated in **Figure 4**, blockchain-enabled smart contracts facilitate streamlined and transparent billing processes, reducing administrative overhead and ensuring fair compensation for healthcare services rendered [38]. In the field of psychology, blockchain enhances data privacy and security in therapeutic settings, enabling confidential and trust-based interactions between therapists and clients. AI-driven virtual assistants equipped with natural language processing capabilities offer personalized support and therapeutic interventions, extending mental health services to remote or underserved populations [39]. ML algorithms analyze patient behavior patterns and sentiment data to customize therapy approaches, optimize treatment efficacy, and monitor mental health progress over time. These use cases demonstrate the synergistic potential of AI, ML, and DLT in revolutionizing healthcare delivery and psychological support, paving the way for enhanced patient outcomes and well-being.

5.1. Case Studies from Finance, Supply Chain, Healthcare, and Other Sectors

In finance, blockchain technology has been leveraged to streamline transactions, enhance security, and reduce fraud [40]. For instance, blockchain-based payment platforms facilitate cross-border transactions with minimal fees and real-time settlement, revolutionizing remittance services. In the supply chain sector, blockchain ensures traceability and transparency throughout the entire supply chain process, from manufacturing to distribution. By recording every transaction on an immutable ledger, blockchain reduces the risk of counterfeit products and ensures the authenticity of goods [41]. Additionally, blockchain-based smart contracts automate and enforce agreements between parties, streamlining contract management and reducing disputes. These case studies highlight the diverse applications of blockchain across various industries, highlighting its potential to drive efficiency, transparency, and trust in the financial, supply chain, healthcare, and other sectors.

5.1.1. Finance

Blockchain technology has significantly transformed the financial sector by revolutionizing transaction processes, bolstering security, and combating fraud [42]. Notably, blockchain-based payment platforms have disrupted cross-border transactions by facilitating real-time settlements with minimal fees, thereby revolutionizing remittance services [43]. Additionally, blockchain's immutable ledger ensures transparency and trust in financial transactions, paving the way for enhanced security and reduced instances of fraud.

5.1.2. Supply Chain

In the supply chain sector, blockchain plays a pivotal role in ensuring transparency and traceability throughout the entire production and distribution process. By recording every transaction on an immutable ledger, blockchain minimizes the risk of counterfeit products and guarantees the authenticity of goods [44]. Furthermore, the implementation of blockchain-based smart contracts automates agreements between stakeholders, streamlining contract management and minimizing disputes.

5.1.3. Healthcare

The integration of AI, ML, and blockchain technologies holds immense promise in the healthcare domain, facilitating secure and transparent management of patient data. By leveraging blockchain for data verification and secure storage, coupled with off-chain computation for AI and ML tasks, healthcare providers can ensure seamless operation while adhering to regulatory standards [45]. These technologies enable real-time diagnostic insights and personalized treatment approaches, thereby enhancing patient care and clinical outcomes.

5.2. Lessons Learned and Best Practices

Through the exploration of real-world use cases, several lessons have emerged

regarding the implementation of AI, ML, and DLT technologies [46]. Firstly, collaboration and interdisciplinary partnerships are essential for successful deployment, requiring cooperation between technologists, domain experts, and stakeholders. Secondly, regulatory compliance and ethical considerations must be prioritized to ensure data privacy, security, and adherence to legal frameworks. Thirdly, user education and training are crucial for fostering adoption and maximizing the benefits of these technologies. By adhering to these best practices and drawing insights from successful use cases, organizations can effectively leverage AI, ML, and DLT to drive innovation, efficiency, and value creation across diverse sectors.

6. Technical Integration of AI and ML Algorithms with Blockchain in Healthcare and Psychiatry

In healthcare and psychiatry, integrating Artificial Intelligence (AI) and Machine Learning (ML) algorithms with blockchain technology requires a carefully structured architecture to achieve efficient operations and ensure regulatory compliance [47]. A practical approach involves offloading computationally demanding AI and ML tasks to an off-chain environment, where data analysis for diagnostics, treatment recommendations, and predictive modelling occurs [48]. This separation allows the system to handle large datasets and complex algorithms without compromising on speed, as blockchain can present limitations in scalability for intensive computation. The processed insights from AI and ML models are then selectively stored on the blockchain for verification and secure access. By encrypting and transferring only the essential outcomes—such as diagnostic results or critical alerts—onto the blockchain, the system maintains data integrity and offers an immutable record, supporting secure and transparent access among healthcare providers without exposing sensitive information [49]. To further enhance the system's responsiveness and scalability, sidechains or state channels can be employed, facilitating parallel processing and higher transaction throughput, which is critical for real-time applications in healthcare and psychiatry.

The workflow begins with patient data collection and initial processing in an off-chain secure environment, followed by AI/ML analysis that identifies patterns or generates personalized treatment recommendations based on historical data [50]. Post-analysis, relevant data points are encrypted and uploaded to the blockchain for immutability and traceability [51]. Providers can then access these results through the blockchain, enabling a secure, decentralized model of information sharing among medical professionals and patients. This integration also enables continuous learning, as patient outcomes and new insights can be fed back into off-chain AI/ML models, enhancing prediction accuracy and treatment personalization over time. By structuring AI, ML, and blockchain integration in this way, healthcare systems can address the dual challenges of computational efficiency and data security, ensuring real-time, data-driven decision-making capabilities that uphold ambitious standards of privacy and compliance.

6.1. Scalability and Performance Considerations

Scalability and performance are paramount in healthcare and psychiatry applications, where timely access to patient data and diagnostic insights is crucial [52]. Traditional blockchain platforms often face limitations in transaction throughput and latency, which can impede the real-time execution of AI and ML tasks. To overcome these challenges, innovative solutions such as sharding, layer 2 scaling solutions, and optimized consensus mechanisms are being explored to enhance the scalability and performance of blockchain networks in healthcare settings [53]. Furthermore, advancements in hardware accelerators like GPUs and TPUs enable accelerated computation of AI and ML algorithms, improving overall system performance and enabling faster diagnostic and treatment decision-making processes.

6.2. Interoperability Challenges and Solutions

Interoperability poses a significant challenge in integrating AI and ML algorithms with blockchain technology in healthcare and psychiatry. Extensive effort has been exerted towards improving the privacy of medical data for patients and healthcare providers by establishing a cryptographic mechanism in the decentralized EHR network or other healthcare applications [54] (Figure 5). Study attempted to develop an efficient mechanism based on ECC above the existing blockchain-based EHR system to achieve the privacy preservation of data accessibility in the network [55]. Study addressed a privacy-preserving platform by establishing an ECC mechanism to encrypt the back-and-forth exchange of medical data stored in the cloud to prevent DDoS cyber-attacks caused by pseudonymity in the blockchain network. The study adopted an inscription mechanism to protect the sharing of medical data privacy in decentralized EHRs, thereby resulting in improved quality and reduced medical treatment costs. Heterogeneous environments with diverse data formats and protocols require standardized interfaces and protocols for seamless data exchange between AI/ML systems and blockchain networks [56]. Initiatives such as the Healthcare Interoperability Alliance and standardized healthcare data exchange protocols aim to bridge disparate systems and facilitate interoperability in healthcare settings [57]. Additionally, middleware solutions and standardized APIs streamline the integration of existing AI and ML frameworks with blockchain technology, enabling interoperability and data portability across healthcare ecosystems.

Successful integration of AI and ML algorithms with blockchain technology in healthcare and psychiatry hinges on tailored strategies to overcome scalability, performance, and interoperability challenges [58]. By leveraging off-chain computation, optimizing blockchain scalability solutions, and promoting interoperability standards, healthcare organizations and psychiatric institutions can unlock the full potential of AI and ML on the blockchain, enhancing patient care, diagnostic accuracy, and treatment outcomes while ensuring data privacy and regulatory compliance.

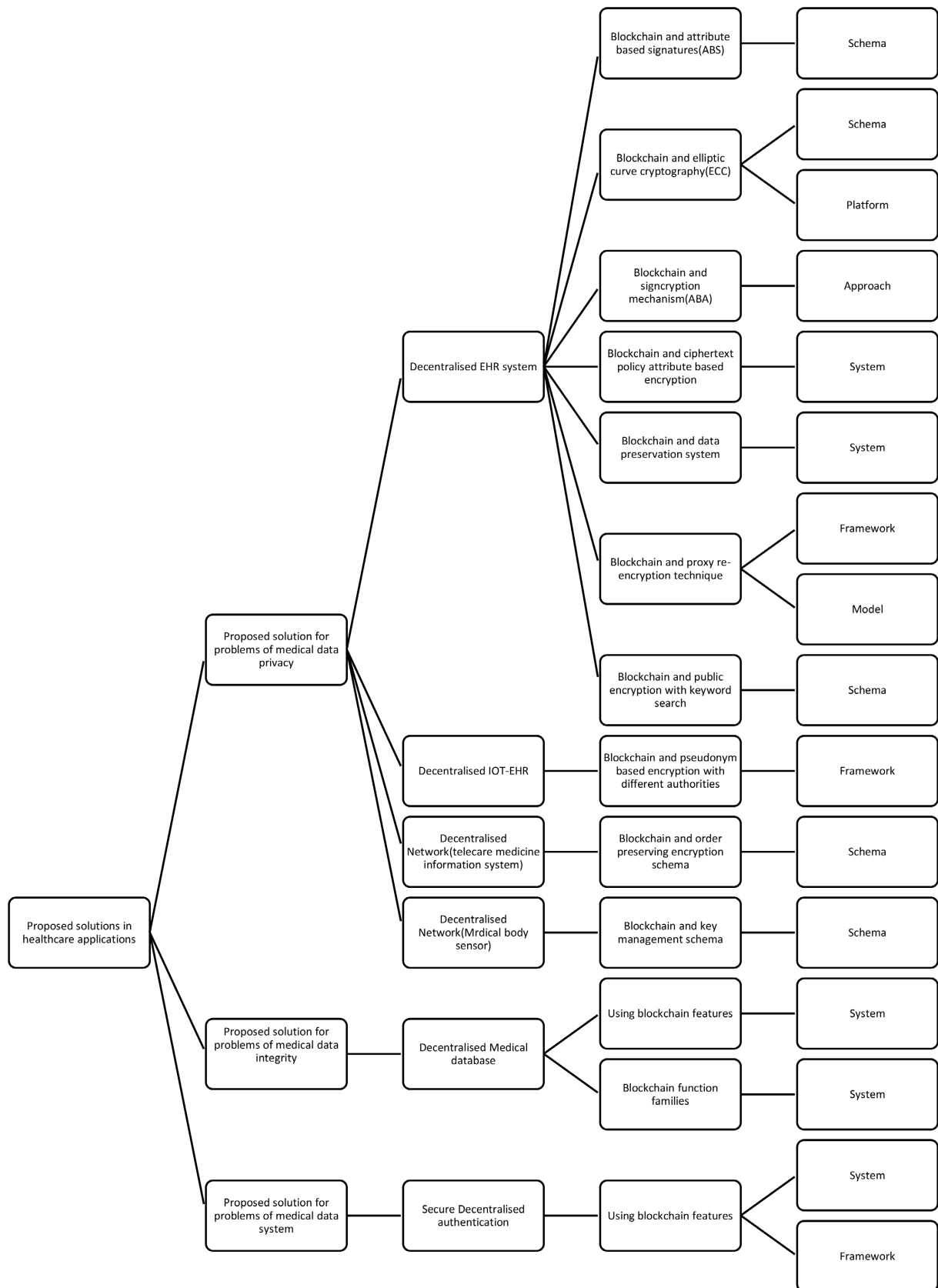


Figure 5. Classification of the proposed solutions for privacy, integrity, and access control problems.

7. Future Directions

Predictions for the future of AI, ML, and DLT convergence in healthcare and psychiatry point to a landscape rich with transformative potential and innovative possibilities. This integration promises groundbreaking advancements in patient care, diagnostic accuracy, and treatment outcomes [59]. In the coming years, AI and ML algorithms are expected to become even more sophisticated, allowing for deeper analysis of healthcare data to derive actionable insights for personalized treatment plans, disease prediction, and preventive care. Meanwhile, blockchain technology will be pivotal in ensuring the security, integrity, and interoperability of healthcare data, fostering transparent, trust-based interactions between patients, healthcare providers, and researchers [60]. The rise of telemedicine and remote monitoring, driven by AI-enabled virtual assistants and wearable devices, will democratize healthcare access, empowering patients to proactively manage their health [61].

7.1. Anticipated Challenges and Technological Barriers

Despite these promising advances, several key challenges lie ahead. Interoperability standards must continue to evolve to support seamless data exchange between diverse healthcare systems, AI models, and blockchain networks. Establishing universally accepted data standards is critical to ensuring that patient data can move securely across platforms without compromising privacy or accessibility [62]. Furthermore, scalability remains a significant concern for blockchain technology, as the computational demands of AI and ML in healthcare increase. Research into blockchain solutions, such as sharding and Layer 2 technologies, could provide pathways to address these scalability issues and facilitate broader adoption in healthcare applications [63].

Explainability in healthcare AI is another pressing challenge, as clinicians and patients alike need to understand the reasoning behind AI-driven recommendations. The “black box” nature of some AI algorithms can create trust issues and hinder clinical adoption. Future research should focus on developing explainable AI models that provide transparency without sacrificing performance, especially in critical areas such as diagnostics and mental health treatment [64].

7.2. Research Directions for Ethical and Practical Advancements

Several avenues for future research could bridge these technological gaps and foster responsible AI-ML-DLT integration in healthcare. One opportunity lies in bridging ethical gaps in data sharing by developing methods that uphold patient confidentiality while allowing secure access for research and treatment [65]. Techniques such as federated learning and homomorphic encryption offer promising solutions, enabling collaborative AI model training across institutions without compromising patient privacy [66]. Another research focus should be on refining AI algorithms to address biases and enhance fairness, particularly in sensitive healthcare applications like mental health. AI models trained on diverse data can

help mitigate biases, ensuring equitable care across different demographics.

Emerging trends in decentralized clinical trials powered by blockchain technology will require specialized protocols to protect patient privacy, support data integrity, and facilitate real-time collaboration among researchers, accelerating the pace of medical research and drug development [67]. Furthermore, AI-enabled chatbots and virtual therapists are likely to play an increasing role in mental health services, offering accessible and personalized support. Research should prioritize optimizing these virtual agents to improve empathy and reliability, ensuring they meet the nuanced needs of mental health patients.

7.3. Implications for Research, Industry, and Policy

As stakeholders in healthcare and psychiatry navigate the opportunities and challenges presented by AI, ML, and DLT, investment in talent development and infrastructure will be essential. Healthcare providers, pharmaceutical companies, and mental health institutions must train personnel in modern technologies to fully harness the benefits of AI-ML-DLT integration. Regulatory bodies will also play a crucial role in establishing frameworks for ethical AI use, data privacy, and cybersecurity [68]. These frameworks are essential for ensuring patient rights and well-being are protected while enabling the responsible deployment of innovative solutions.

In summary, the convergence of AI, ML, and DLT has the potential to reshape healthcare and psychiatry by enhancing personalization, security, and accessibility [69]. By addressing scalability, interoperability, and explainability challenges, and by prioritizing ethical practices in data sharing and algorithmic fairness, future research can pave the way for a sustainable and responsible technological evolution in healthcare.

8. Implementation Guidelines

Practical guidelines for implementing AI-ML-DLT solutions in healthcare and psychiatry are essential for ensuring successful deployment and maximizing the benefits of these technologies in patient care and mental health outcomes. Primarily, organizations should prioritize patient-centric approaches, focusing on solutions that enhance clinical workflows, streamline administrative processes, and ultimately improve patient experiences [70]. Establishing clear objectives and well-defined use cases for AI, ML, and DLT applications is imperative to align technology investments with strategic priorities and organizational goals.

8.1. Responsible Innovation Framework

Within the context of healthcare and mental health, it is critical to approach the development and deployment of AI, ML, and DLT with a framework for responsible innovation [71]. This involves aligning with established industry guidelines and best practices, such as those recommended by IEEE for ethical AI and the WHO for health data use [72]. Responsible AI, ML, and DLT in healthcare means

prioritizing transparency, accountability, and fairness in how data is collected, processed, and used. For example, transparency can be achieved through explainable AI models that allow healthcare professionals and patients to understand how decisions are made. Accountability requires robust governance structures that define clear roles for stakeholders involved in data handling and system oversight [73]. Fairness, especially in mental health applications, necessitates actively addressing biases in data and algorithms to ensure equitable outcomes across diverse patient populations.

Furthermore, ethical considerations specific to mental health data include consent management, where patients have clear control over their data, and data minimization, limiting data collection to only what is essential for the intended use. This approach respects patient privacy while maintaining compliance with regulations such as GDPR and HIPAA, ensuring that AI-ML-DLT implementations are both legally sound and ethically responsible [74].

8.2. Development and Deployment Frameworks

Frameworks and tools for development and deployment play a pivotal role in facilitating the integration of AI, ML, and DLT into healthcare and psychiatric practices. Healthcare-specific interoperability frameworks like FHIR (Fast Healthcare Interoperability Resources) and HL7 (Health Level Seven International) provide standardized data formats and protocols to ensure seamless data exchange between systems, promoting interoperability [75]. Additionally, open-source ML libraries and development platforms, such as TensorFlow and PyTorch, offer robust tools for building and training AI models tailored to healthcare, allowing for rapid innovation with reliable technical support [76]. For DLT, blockchain frameworks like Hyperledger Fabric and Ethereum provide infrastructure for building secure, decentralized healthcare applications, ensuring data integrity and transparency across patient-provider interactions [77].

8.3. Risk Management and Security Considerations

In healthcare and psychiatry, managing risk and ensuring security are paramount due to the sensitive nature of patient data. Implementing robust cybersecurity measures, such as encryption, access controls, and multi-factor authentication, is essential to protect patient information at rest and in transit. These measures safeguard against unauthorized access and data breaches, helping to build patient trust in AI-ML-DLT systems. Furthermore, organizations must comply with regulatory standards like HIPAA and GDPR, which set legal requirements for handling and processing patient data [78]. Meeting these standards ensures the ethical management of sensitive health information and aligns with the principles outlined in the Responsible Innovation Framework.

By incorporating a responsible innovation framework alongside structured development tools and rigorous security protocols, healthcare and psychiatry organizations can leverage AI, ML, and DLT technologies to improve patient outcomes

while upholding ethical and legal standards [79]. This structured approach not only enhances operational efficiency but also fosters trust, equity, and accountability in healthcare applications.

9. Collaboration and Community Building in Healthcare and Psychiatry

In the fields of healthcare and psychiatry, interdisciplinary collaboration is essential, especially when integrating Artificial Intelligence (AI), Machine Learning (ML), and Distributed Ledger Technology (DLT) to drive innovation and enhance patient outcomes [80]. This collaboration involves bringing together healthcare professionals, psychiatrists, data scientists, blockchain developers, and researchers, each contributing their expertise to tackle complex challenges and develop transformative solutions. To operationalize such collaboration, structured models can be established that clearly outline roles, workflows, and responsibilities for each group. For example, healthcare professionals provide domain knowledge on patient needs and clinical requirements, data scientists and AI experts build predictive models, and blockchain developers ensure data security and compliance through decentralized data management [81]. A shared project management framework can facilitate coordination, enabling all parties to align on project goals, timelines, and deliverables. Effective interdisciplinary collaboration is also fostered through cross-disciplinary training sessions where team members can learn the basics of each other's fields. For instance, training healthcare practitioners in AI ethics and familiarizing data scientists with mental health frameworks can enhance mutual understanding and create synergy in developing AI-ML-DLT applications for healthcare. Additionally, collaborative validation processes can be introduced to ensure AI models are dependable and relevant to clinical practice [82]. This might include joint validation sessions where healthcare providers review model outputs with data scientists, refining algorithms based on real-world clinical feedback.

Initiatives that promote innovation and knowledge exchange play a pivotal role in supporting interdisciplinary efforts. Academic institutions, research organizations, and industry partners can establish collaborative platforms such as research consortia, hackathons, and innovation hubs to encourage cross-disciplinary dialogue, share knowledge, and co-create solutions. These platforms provide practical opportunities for healthcare practitioners, researchers, and technologists to work together on projects, exchange best practices, and explore emerging trends in AI, ML, and DLT applications for healthcare and psychiatry. Building communities of practice around AI-ML-DLT integration further supports collaboration, enabling professionals to exchange ideas, address shared challenges, and stay updated on advancements in the field. Online forums, professional associations, and networking events act as valuable platforms for community members to connect, gain insights, and remain informed on technological and healthcare developments. By fostering structured interdisciplinary collaboration and building

vibrant communities of practice, stakeholders in healthcare and psychiatry can leverage the collective expertise of diverse professionals [83]. This collaborative ecosystem not only addresses complex challenges but also enhances patient care, shapes future healthcare delivery, and facilitates the convergence of AI, ML, and DLT for the benefit of mental health and well-being.

10. Conclusion

In conclusion, the integration of Artificial Intelligence (AI), Machine Learning (ML), and Distributed Ledger Technology (DLT) holds immense promise for transforming healthcare and psychiatry, ushering in a new era of innovation, efficiency, and patient-centered care. Throughout this discourse, key findings and insights have underscored the transformative potential of these technologies in improving diagnostic accuracy, treatment efficacy, and patient outcomes, while also highlighting the importance of interdisciplinary collaboration, regulatory compliance, and ethical considerations. Researchers, practitioners, and policy-makers alike are called to action to embrace the opportunities presented by blockchain brains in healthcare and psychiatry [84]. By fostering interdisciplinary collaboration, leveraging emerging technologies, and prioritizing patient-centric approaches, stakeholders can drive innovation, address healthcare disparities, and enhance mental health services for all individuals. Moreover, there is a pressing need for policymakers to establish robust regulatory frameworks and ethical guidelines to ensure the responsible and equitable deployment of AI, ML, and DLT in healthcare and psychiatry settings. Looking ahead, the vision for the future of blockchain brains in healthcare and psychiatry is one of continuous innovation, collaboration, and empowerment. By harnessing the synergies between AI, ML, and DLT, stakeholders can unlock new opportunities for personalized medicine, predictive analytics, and decentralized healthcare delivery [85]. Furthermore, the integration of blockchain technology ensures the security, integrity, and interoperability of healthcare data, fostering trust and transparency in patient-provider interactions and enabling seamless collaboration across healthcare ecosystems [86].

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Conflicts of Interest

The authors declare no conflicts of interest.

References

- [1] Azrour, M., Mabrouki, J., Guezzaz, A., Ahmad, S., Khan, S. and Benkirane, S. (2024) IoT, Machine Learning and Data Analytics for Smart Healthcare. CRC Press.
- [2] Russell, S. (2021) Human-Compatible Artificial Intelligence. In: Muggleton, S. and Chater, N., Eds., *Human-Like Machine Intelligence*, Oxford University Press, 3-23. <https://doi.org/10.1093/oso/9780198862536.003.0001>
- [3] Raschka, S., Patterson, J. and Nolet, C. (2020) Machine Learning in Python: Main Developments and Technology Trends in Data Science, Machine Learning, and Artificial Intelligence. *Information*, **11**, Article No. 193. <https://doi.org/10.3390/info11040193>
- [4] Prashanth Joshi, A., Han, M. and Wang, Y. (2018) A Survey on Security and Privacy Issues of Blockchain Technology. *Mathematical Foundations of Computing*, **1**, 121-147. <https://doi.org/10.3934/mfc.2018007>
- [5] Singh, Y., Jabbar, M.A., Kumar Shandilya, S., Vovk, O. and Hnatiuk, Y. (2023) Exploring Applications of Blockchain in Healthcare: Road Map and Future Directions. *Frontiers in Public Health*, **11**, Article ID: 1229386. <https://doi.org/10.3389/fpubh.2023.1229386>
- [6] Mohd Ali, F., Md Yunus, N.A., Mohamed, N.N., Mat Daud, M. and A. Sundararajan, E. (2023) A Systematic Mapping: Exploring Internet of Everything Technologies and Innovations. *Symmetry*, **15**, Article No. 1964. <https://doi.org/10.3390/sym15111964>
- [7] Henke, N. and Bughin, L.J. (2016) The Age of Analytics: Competing in a Data-Driven World.
- [8] Schaffers, H., Vartiainen, M. and Bus, J. (2022) Digital Innovation and the Future of Work. CRC Press.
- [9] Imoize, A.L., Adedeji, O., Tandiya, N. and Shetty, S. (2021) 6G Enabled Smart Infrastructure for Sustainable Society: Opportunities, Challenges, and Research Roadmap. *Sensors*, **21**, Article No. 1709. <https://doi.org/10.3390/s21051709>
- [10] Vuong, Q.P. (2024) The Potential for Artificial Intelligence and Machine Learning in Healthcare: The Future of Healthcare through Smart Technologies.
- [11] Ali, A., Rahouti, M., Latif, S., Kanhere, S., Singh, J., Janjua, U., *et al.* (2019) Blockchain and the Future of the Internet: A Comprehensive Review.
- [12] Siyal, A.A., Junejo, A.Z., Zawish, M., Ahmed, K., Khalil, A. and Soursou, G. (2019) Applications of Blockchain Technology in Medicine and Healthcare: Challenges and Future Perspectives. *Cryptography*, **3**, Article No. 3. <https://doi.org/10.3390/cryptography3010003>
- [13] Solomonoff, R.J. (1997) The Discovery of Algorithmic Probability. *Journal of Computer and System Sciences*, **55**, 73-88. <https://doi.org/10.1006/jcss.1997.1500>
- [14] Husain, A. (2017) The Sentient Machine: The Coming Age of Artificial Intelligence. Simon and Schuster.
- [15] Minsky, M. (1961) Steps toward Artificial Intelligence. *Proceedings of the IRE*, **49**, 8-30. <https://doi.org/10.1109/jrproc.1961.287775>
- [16] Stoica, I., Song, D., Popa, R.A., Patterson, D., Mahoney, R M.W., *et al.* (2017) A Berkeley View of Systems Challenges for AI.
- [17] Nasir, Y.S. and Guo, D. (2019) Multi-Agent Deep Reinforcement Learning for Dynamic Power Allocation in Wireless Networks. *IEEE Journal on Selected Areas in Communications*, **37**, 2239-2250. <https://doi.org/10.1109/jsac.2019.2933973>
- [18] Usama, M., Qadir, J., Raza, A., Arif, H., Yau, K.A., Elkhatib, Y., *et al.* (2019)

- Unsupervised Machine Learning for Networking: Techniques, Applications and Research Challenges. *IEEE Access*, **7**, 65579-65615.
<https://doi.org/10.1109/access.2019.2916648>
- [19] Al-Jarrah, O.Y., Yoo, P.D., Muhaidat, S., Karagiannidis, G.K. and Taha, K. (2015) Efficient Machine Learning for Big Data: A Review. *Big Data Research*, **2**, 87-93.
<https://doi.org/10.1016/j.bdr.2015.04.001>
- [20] Rauchs, M., Glidden, A., Gordon, B., Pieters, G.C., Recanatini, M., Rostand, F., *et al* (2018) Distributed Ledger Technology Systems: A Conceptual Framework. *SSRN Electronic Journal*. <https://doi.org/10.2139/ssrn.3230013>
- [21] Azaria, A., Ekblaw, A., Vieira, T. and Lippman, A. (2016) Medrec: Using Blockchain for Medical Data Access and Permission Management. 2016 *2nd International Conference on Open and Big Data (OBD)*, Vienna, 22-24 August 2016, 25-30.
<https://doi.org/10.1109/obd.2016.11>
- [22] Werbach, K. (2018) Trust, but Verify: Why the Blockchain Needs the Law. *Berkeley Technology Law Journal*, **33**, 487-550.
- [23] Baliga, A. (2017) Understanding Blockchain Consensus Models. *Persistent*, **4**, 1-14.
- [24] Bashir, I. (2017) Mastering Blockchain. Packt Publishing Ltd.
- [25] Bheemaiah, K. (2017) The Blockchain Alternative: Rethinking Macroeconomic Policy and Economic Theory. Apress.
- [26] Quatrini, S. (2021) Challenges and Opportunities to Scale up Sustainable Finance after the COVID-19 Crisis: Lessons and Promising Innovations from Science and Practice. *Ecosystem Services*, **48**, Article ID: 101240.
<https://doi.org/10.1016/j.ecoser.2020.101240>
- [27] Xuan, T.R. and Ness, S. (2023) Integration of Blockchain and AI: Exploring Application in the Digital Business. *Journal of Engineering Research and Reports*, **25**, 20-39.
<https://doi.org/10.9734/jerr/2023/v25i8955>
- [28] Chirra, D.R. (2024) Secure Data Sharing in Multi-Cloud Environments: A Cryptographic Framework for Healthcare Systems. *Revista de Inteligencia Artificial en Medicina*, **15**, 821-843.
- [29] Mendelson, D. and Mendelson, D. (2017) Legal Protections for Personal Health Information in the Age of Big Data—A Proposal for Regulatory Framework. *Ethics, Medicine and Public Health*, **3**, 37-55. <https://doi.org/10.1016/j.jemep.2017.02.005>
- [30] Khalid, M.I., Ahmed, M. and Kim, J. (2023) Enhancing Data Protection in Dynamic Consent Management Systems: Formalizing Privacy and Security Definitions with Differential Privacy, Decentralization, and Zero-Knowledge Proofs. *Sensors*, **23**, Article No. 7604. <https://doi.org/10.3390/s23177604>
- [31] Timmons, A.C., Duong, J.B., Simo Fiallo, N., Lee, T., Vo, H.P.Q., Ahle, M.W., *et al* (2022) A Call to Action on Assessing and Mitigating Bias in Artificial Intelligence Applications for Mental Health. *Perspectives on Psychological Science*, **18**, 1062-1096. <https://doi.org/10.1177/17456916221134490>
- [32] Jabarulla, M.Y. and Lee, H. (2021) A Blockchain and Artificial Intelligence-Based, Patient-Centric Healthcare System for Combating the COVID-19 Pandemic: Opportunities and Applications. *Healthcare*, **9**, Article No. 1019.
<https://doi.org/10.3390/healthcare9081019>
- [33] D'Alfonso, S. (2020) AI in Mental Health. *Current Opinion in Psychology*, **36**, 112-117. <https://doi.org/10.1016/j.copsyc.2020.04.005>
- [34] Velmovitsky, P.E., Bublitz, F.M., Fadrique, L.X. and Morita, P.P. (2021) Blockchain Applications in Health Care and Public Health: Increased Transparency. *JMIR*

- Medical Informatics*, **9**, e20713. <https://doi.org/10.2196/20713>
- [35] World Health Organization (2021) Ethics and Governance of Artificial Intelligence for Health: WHO Guidance.
- [36] Trenfield, S.J., Awad, A., McCoubrey, L.E., Elbadawi, M., Goyanes, A., Gaisford, S., *et al.* (2022) Advancing Pharmacy and Healthcare with Virtual Digital Technologies. *Advanced Drug Delivery Reviews*, **182**, Article ID: 114098. <https://doi.org/10.1016/j.addr.2021.114098>
- [37] Ahmed, Z., Mohamed, K., Zeeshan, S. and Dong, X. (2020) Artificial Intelligence with Multi-Functional Machine Learning Platform Development for Better Healthcare and Precision Medicine. *Database*, **2020**, baaa010. <https://doi.org/10.1093/database/baaa010>
- [38] Jeong, S., Shen, J. and Ahn, B. (2021) A Study on Smart Healthcare Monitoring Using IoT Based on Blockchain. *Wireless Communications and Mobile Computing*, **2021**, Article ID: 9932091. <https://doi.org/10.1155/2021/9932091>
- [39] Olawade, D.B., Wada, O.Z., Odetayo, A., David-Olawade, A.C., Asaolu, F. and Eberhardt, J. (2024) Enhancing Mental Health with Artificial Intelligence: Current Trends and Future Prospects. *Journal of Medicine, Surgery, and Public Health*, **3**, Article ID: 100099. <https://doi.org/10.1016/j.glmedi.2024.100099>
- [40] Dutta, P., Choi, T., Somani, S. and Butala, R. (2020) Blockchain Technology in Supply Chain Operations: Applications, Challenges and Research Opportunities. *Transportation Research Part E: Logistics and Transportation Review*, **142**, Article ID: 102067. <https://doi.org/10.1016/j.tre.2020.102067>
- [41] Yiu, N.C.K. (2021) Toward Blockchain-Enabled Supply Chain Anti-Counterfeiting and Traceability. *Future Internet*, **13**, Article No. 86. <https://doi.org/10.3390/fi13040086>
- [42] Parate, S., Josyula, H.P. and Reddi, L.T. (2023) Digital Identity Verification: Transforming KYC Processes in Banking through Advanced Technology and Enhanced Security Measures. *International Research Journal of Modernization in Engineering Technology and Science*, **5**, 128-137.
- [43] Flore, M. (2018) How Blockchain-Based Technology Is Disrupting Migrants' Remittances: A Preliminary Assessment. Luxembourg, EUR 29492.
- [44] Uddin, M. (2021) Blockchain Medledger: Hyperledger Fabric Enabled Drug Traceability System for Counterfeit Drugs in Pharmaceutical Industry. *International Journal of Pharmaceutics*, **597**, Article ID: 120235. <https://doi.org/10.1016/j.ijpharm.2021.120235>
- [45] Huang, G. and Foysal, A.A. (2021) Blockchain in Healthcare. *Technology and Investment*, **12**, 168-181. <https://doi.org/10.4236/ti.2021.123010>
- [46] Li, J. and Kassem, M. (2021) Applications of Distributed Ledger Technology (DLT) and Blockchain-Enabled Smart Contracts in Construction. *Automation in Construction*, **132**, Article ID: 103955. <https://doi.org/10.1016/j.autcon.2021.103955>
- [47] Filippis, R.d. and Foysal, A.A. (2024) Securing Predictive Psychological Assessments: The Synergy of Blockchain Technology and Artificial Intelligence. *OALib*, **11**, e12378. <https://doi.org/10.4236/oalib.1112378>
- [48] Aminizadeh, S., Heidari, A., Dehghan, M., Toumaj, S., Rezaei, M., Jafari Navimipour, N., *et al.* (2024) Opportunities and Challenges of Artificial Intelligence and Distributed Systems to Improve the Quality of Healthcare Service. *Artificial Intelligence in Medicine*, **149**, Article ID: 102779. <https://doi.org/10.1016/j.artmed.2024.102779>
- [49] Yaqoob, I., Salah, K., Jayaraman, R. and Al-Hammadi, Y. (2022) Blockchain for

- Healthcare Data Management: Opportunities, Challenges, and Future Recommendations. *Neural Computing and Applications*, **34**, 11475-11490.
- [50] Murala, D.K., Panda, S.K. and Dash, S.P. (2023) Medmetaverse: Medical Care of Chronic Disease Patients and Managing Data Using Artificial Intelligence, Blockchain, and Wearable Devices State-of-the-Art Methodology. *IEEE Access*, **11**, 138954-138985. <https://doi.org/10.1109/access.2023.3340791>
- [51] Guo, X., Khalid, M.A., Domingos, I., Michala, A.L., Adriko, M., Rowel, C., *et al* (2021) Smartphone-Based DNA Diagnostics for Malaria Detection Using Deep Learning for Local Decision Support and Blockchain Technology for Security. *Nature Electronics*, **4**, 615-624. <https://doi.org/10.1038/s41928-021-00612-x>
- [52] Harerimana, G., Jang, B., Kim, J.W. and Park, H.K. (2018) Health Big Data Analytics: A Technology Survey. *IEEE Access*, **6**, 65661-65678. <https://doi.org/10.1109/access.2018.2878254>
- [53] Hafid, A., Hafid, A.S. and Samih, M. (2020) Scaling Blockchains: A Comprehensive Survey. *IEEE Access*, **8**, 125244-125262. <https://doi.org/10.1109/access.2020.3007251>
- [54] Hussien, H.M., Yasin, S.M., Udzir, S.N.I., Zaidan, A.A. and Zaidan, B.B. (2019) A Systematic Review for Enabling of Develop a Blockchain Technology in Healthcare Application: Taxonomy, Substantially Analysis, Motivations, Challenges, Recommendations and Future Direction. *Journal of Medical Systems*, **43**, Article No. 320. <https://doi.org/10.1007/s10916-019-1445-8>
- [55] Shamshad, S., Minahil, Mahmood, K., Kumari, S. and Chen, C. (2020) A Secure Blockchain-Based E-Health Records Storage and Sharing Scheme. *Journal of Information Security and Applications*, **55**, Article ID: 102590. <https://doi.org/10.1016/j.jisa.2020.102590>
- [56] Gill, S.S., Golec, M., Hu, J., Xu, M., Du, J., Wu, H., *et al.* (2024) Edge AI: A Taxonomy, Systematic Review and Future Directions. *Cluster Computing*, **28**, 1-53. <https://doi.org/10.1007/s10586-024-04686-y>
- [57] Bhartiya, S. and Mehrotra, D. (2015) Challenges and Recommendations to Healthcare Data Exchange in an Interoperable Environment. *Electronic Journal of Health Informatics*, **8**, e16.
- [58] Tariq, M.U. (2024) Revolutionizing Health Data Management with Blockchain Technology: Enhancing Security and Efficiency in a Digital Era. In: Garcia, M.B. and de Almeida, R.P.P. Eds., *Emerging Technologies for Health Literacy and Medical Practice*, IGI Global, 153-175. <https://doi.org/10.4018/979-8-3693-1214-8.ch008>
- [59] Jim, J.R., Hosain, M.T., Mridha, M.F., Kabir, M.M. and Shin, J. (2023) Toward Trustworthy Metaverse: Advancements and Challenges. *IEEE Access*, **11**, 118318-118347. <https://doi.org/10.1109/access.2023.3326258>
- [60] Carlos Ferreira, J., Elvas, L.B., Correia, R. and Mascarenhas, M. (2024) Enhancing EHR Interoperability and Security through Distributed Ledger Technology: A Review. *Healthcare*, **12**, Article No. 1967. <https://doi.org/10.3390/healthcare12191967>
- [61] Ahmed, T. (2024) AI-Enabled Healthcare Sector: Futures Business Models. Master's Thesis, T. Ahmed.
- [62] Thapa, C. and Camtepe, S. (2021) Precision Health Data: Requirements, Challenges and Existing Techniques for Data Security and Privacy. *Computers in Biology and Medicine*, **129**, Article ID: 104130. <https://doi.org/10.1016/j.combiomed.2020.104130>
- [63] Sanka, A.I. and Cheung, R.C.C. (2021) A Systematic Review of Blockchain Scalability: Issues, Solutions, Analysis and Future Research. *Journal of Network and Computer*

- Applications*, **195**, Article ID: 103232. <https://doi.org/10.1016/j.jnca.2021.103232>
- [64] Marey, A., Arjmand, P., Alerab, A.D.S., Eslami, M.J., Saad, A.M., Sanchez, N., *et al.* (2024) Explainability, Transparency and Black Box Challenges of AI in Radiology: Impact on Patient Care in Cardiovascular Radiology. *Egyptian Journal of Radiology and Nuclear Medicine*, **55**, 1-14. <https://doi.org/10.1186/s43055-024-01356-2>
- [65] James, R., Tsosie, R., Sahota, P., Parker, M., Dillard, D., Sylvester, I., *et al.* (2014) Exploring Pathways to Trust: A Tribal Perspective on Data Sharing. *Genetics in Medicine*, **16**, 820-826. <https://doi.org/10.1038/gim.2014.47>
- [66] Ali, M., Naeem, F., Tariq, M. and Kaddoum, G. (2023) Federated Learning for Privacy Preservation in Smart Healthcare Systems: A Comprehensive Survey. *IEEE Journal of Biomedical and Health Informatics*, **27**, 778-789. <https://doi.org/10.1109/jbhi.2022.3181823>
- [67] Krishnan, S. (2024) Democratizing Clinical Trial Data with Blockchain for Personalized Medicine: A People-Planet-Profit Approach. In: Mishra, R., Dwivedi, V. and Saxena, S., Eds., *Computational Convergence and Interoperability in Electronic Health Records*, IGI Global, 305-320. <https://doi.org/10.4018/979-8-3693-3989-3.ch016>
- [68] Nguyen, M.T. and Tran, M.Q. (2023) Balancing Security and Privacy in the Digital Age: An In-Depth Analysis of Legal and Regulatory Frameworks Impacting Cybersecurity Practices. *International Journal of Intelligent Automation and Computing*, **6**, 1-12.
- [69] Hajizadeh, M., Alaeddini, M. and Reaidy, P. (2023) Bibliometric Analysis on the Convergence of Artificial Intelligence and Blockchain. In: Prieto, J., *et al.*, Eds., *International Congress on Blockchain and Applications*, Springer International Publishing, 334-344. https://doi.org/10.1007/978-3-031-21229-1_31
- [70] Omaghomi, T.T., Akomolafe, O., Onwumere, C., Odilibe, I.P. and Elufioye, O.A. (2024) Patient Experience and Satisfaction in Healthcare: A Focus on Managerial Approaches—A Review. *International Medical Science Research Journal*, **4**, 194-209. <https://doi.org/10.51594/imsrj.v4i2.812>
- [71] Williamson, S.M. and Prybutok, V. (2024) Balancing Privacy and Progress: A Review of Privacy Challenges, Systemic Oversight, and Patient Perceptions in AI-Driven Healthcare. *Applied Sciences*, **14**, Article No. 675. <https://doi.org/10.3390/app14020675>
- [72] Nasir, S., Khan, R.A. and Bai, S. (2024) Ethical Framework for Harnessing the Power of AI in Healthcare and beyond. *IEEE Access*, **12**, 31014-31035. <https://doi.org/10.1109/access.2024.3369912>
- [73] Sargiotis, D. (2024) Overview and Importance of Data Governance. In: Sargiotis, D., Ed., *Data Governance*, Springer Nature, 1-85. https://doi.org/10.1007/978-3-031-67268-2_1
- [74] Cohen, I.G., Gerke, S. and Kramer, D.B. (2020) Ethical and Legal Implications of Remote Monitoring of Medical Devices. *The Milbank Quarterly*, **98**, 1257-1289. <https://doi.org/10.1111/1468-0009.12481>
- [75] Gohar, A.N., Abdelmawgoud, S.A. and Farhan, M.S. (2022) A Patient-Centric Healthcare Framework Reference Architecture for Better Semantic Interoperability Based on Blockchain, Cloud, and IoT. *IEEE Access*, **10**, 92137-92157. <https://doi.org/10.1109/access.2022.3202902>
- [76] Nguyen, G., Dlugolinsky, S., Bobák, M., Tran, V., López García, Á., Heredia, I., *et al.* (2019) Machine Learning and Deep Learning Frameworks and Libraries for Large-Scale Data Mining: A Survey. *Artificial Intelligence Review*, **52**, 77-124.

- <https://doi.org/10.1007/s10462-018-09679-z>
- [77] Khatoon, A. (2020) A Blockchain-Based Smart Contract System for Healthcare Management. *Electronics*, **9**, Article No. 94. <https://doi.org/10.3390/electronics9010094>
- [78] Silva, I. and Soto, M. (2022) Privacy-Preserving Data Sharing in Healthcare: An In-Depth Analysis of Big Data Solutions and Regulatory Compliance. *International Journal of Applied Health Care Analytics*, **7**, 14-23.
- [79] Sabharwal, S.M., Chhabra, S. and Aiden, M.K. (2024) AI and Blockchain for Secure Data Analytics. In: Kaushik, K. and Sharma, I., Eds., *Next-Generation Cybersecurity*, Springer Nature, 39-81. https://doi.org/10.1007/978-981-97-1249-6_3
- [80] Bhumichai, D., Smiliotopoulos, C., Benton, R., Kambourakis, G. and Damopoulos, D. (2024) The Convergence of Artificial Intelligence and Blockchain: The State of Play and the Road Ahead. *Information*, **15**, Article No. 268. <https://doi.org/10.3390/info15050268>
- [81] Prashanth, M.S., Karnati, R., Velpuru, M.S. and Venkateshwara Reddy, H. (2024) Enhancing Health Record Security and Privacy with Blockchain-Based Access Management. In: *Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering*, Springer Nature Switzerland, 182-202. https://doi.org/10.1007/978-3-031-66044-3_13
- [82] Bakas, S., Vollmuth, P., Galdiks, N., Booth, T.C., Aerts, H.J.W.L., Bi, W.L., *et al* (2024) Artificial Intelligence for Response Assessment in Neuro Oncology (AI-RANO), Part 2: Recommendations for Standardisation, Validation, and Good Clinical Practice. *The Lancet Oncology*, **25**, e589-e601. [https://doi.org/10.1016/s1470-2045\(24\)00315-2](https://doi.org/10.1016/s1470-2045(24)00315-2)
- [83] Zamiri, M. and Esmaeili, A. (2024) Strategies, Methods, and Supports for Developing Skills within Learning Communities: A Systematic Review of the Literature. *Administrative Sciences*, **14**, Article No. 231. <https://doi.org/10.3390/admsci14090231>
- [84] Balasubramanian, S., Shukla, V., Sethi, J.S., Islam, N. and Saloum, R. (2021) A Readiness Assessment Framework for Blockchain Adoption: A Healthcare Case Study. *Technological Forecasting and Social Change*, **165**, Article ID: 120536. <https://doi.org/10.1016/j.techfore.2020.120536>
- [85] Hammad, A. and Abu-Zaid, R. (2024) Applications of AI in Decentralized Computing Systems: Harnessing Artificial Intelligence for Enhanced Scalability, Efficiency, and Autonomous Decision-Making in Distributed Architectures. *Applied Research in Artificial Intelligence and Cloud Computing*, **7**, 161-187.
- [86] Thangamani, R., Kamalam, G.K. and Vimaladevi, M. (2024) Revolutionizing Healthcare Processes: The Dynamic Role of Blockchain Innovation. In: Kumar, P. and Kumari, A., Eds., *Blockchain for Bio-Medical Research and Healthcare: Concept, Trends, and Future Implications*, Springer Nature, 229-267. https://doi.org/10.1007/978-981-97-4268-4_10