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Machine Learning and Artificial Intelligence for Next-Generation Intelligent Data Analytics: A Cross-Domain Review of Healthcare, Cybersecurity, Blockchain, and Supply Chains

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ABSTRACT

In the rapidly evolving landscape of today's world, Artificial Intelligence (AI) and Machine Learning (ML) are revolutionizing intelligent data analytics, empowering decision-making across various sectors with enhanced data-driven insights. This review covers concepts from the foundation up, next-generation analytic techniques, cross-domain applications and some key challenges as well as future directions. Supervised, unsupervised and reinforcement learning are some of the core ML approaches which enable predictive and adaptive systems. Real-time analytics, edge computing, and explainable AI are some of the emerging technologies that improve efficiency and transparency. Healthcare, cybersecurity, blockchain and supply chain management are all examples of areas where we see considerable advances in prediction, security, and optimization. But data challenges like privacy, quality, data scalability, and ethical issues remain. The future of federated learning, quantum computing, and autonomous systems, among other trends, holds the potential of continued innovation, propelling intelligent, secure, and scalable analytics ecosystems across the globe.

INTRODUCTION

Artificial Intelligence (AI) and Machine Learning (ML) have grown into an exciting technology that is changing the way data is gathered, processed, analyzed and used in several industries. Today, in the digital age, data is generated at an unprecedented rate from sensor, social media, enterprise and IoT systems, with a pressing need for intelligent analytics solutions that can efficiently and accurately

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harness the meaning from this data [1]. Conventional data processing techniques are no longer adequate to deal with the deluge of data, the speed at which it arrives and the diversity of its sources in the current big data world. Consequently, intelligent analytics systems leveraging AI and ML technologies are crucial for providing data-driven insights across dynamic and complex environments [2].

The journey of intelligent data analytics starts with simple statistics and extends to sophisticated predictive and prescriptive analytics, leveraging machine learning algorithms. The first systems were more descriptive in nature and explained what had happened in the past [3]. With the recent improvements in computational power and development of algorithms, modern systems have come a long way from just predictive models to include prescriptive models that recommend optimal actions for the future. With the advent of deep learning, neural networks and reinforcement learning, systems are able to learn from massive, unstructured data like images, text and sensor streams [4].

The key driver behind this review is the growing integration of AI and ML in various applications including health care, cyber security, blockchain, and supply chain systems. Such domains include complex data structures, high security needs, and critical decision-making systems where the need for accuracy and reliability in data analysis is paramount [5]. In the medical industry, AI analytics helps with early disease detection, personalized treatment, and efficient hospital management. In the field of cybersecurity, ML algorithms are employed for anomaly detection, to thwart cyberattacks, and to fortify systems. AI brings several advantages to blockchain systems, such as better fraud identification, optimization of smart contracts, and better security measures [6]. Likewise, the systems involved in the supply chain use smart analytics for predicting demand, logistics optimization, and risk reduction.

While there are great strides being made, there are also a number of challenges in implementing AI and ML for Intelligent Data Analytics. Problems of privacy, model interpretability, algorithm bias and computational constraints continue to be key obstacles to the general adoption. Also, adding AI systems to legacy infrastructure systems brings technical and operational challenges. Additionally, the rise of reliance on automated decision-making processes, especially in sensitive sectors such as healthcare and finance, raises ethical issues [7].

This review is intended to give a concrete overview of the current trends, challenges and future directions of AI and ML based Intelligent Data Analytics in various domains. It focuses on understanding how these technologies are changing to serve the needs of today's data ecosystems and what impact they could have on decision making processes. This research highlights the need for scalable, transparent, and secure AI systems that can tackle real-world problems effectively, through

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the lens of cross-domain applications. The introduction provides a solid background for the reader by defining the scope and context of the introduction of AI and ML in the next generation of intelligent data analytics systems, and laying the groundwork for the rest of the review, which will examine the techniques, applications, and potentials of AI and ML.

AI AND ML FUNDAMENTALS

The core technique that is fundamental to today's intelligent data analytics systems is Artificial Intelligence (AI) and Machine Learning (ML). These are basic concepts, learning models, computational models, and methods of data processing that allow machines to mimic human intelligence and processes, including learning from experience, pattern recognition, and decision-making [8]. Knowing these building blocks is crucial for creating and executing successful AI-powered analytics solutions in different areas [9].

In essence, Artificial Intelligence is the umbrella term for work done in the development of systems that can do things which normally require human intelligence. They involve reasoning, problem-solving, perception, language processing and decision-making. Machine Learning, a branch of AI, concentrates on creating algorithms that enable a system to learn from data without explicit programming [10]. Rather than having a set of rules, ML models find patterns within data and get better with each new unit of data.

There are three main types of Machine Learning techniques: Supervised, Unsupervised, and Reinforcement. Supervised learning is learning from a training set that provides labels on the inputs and the outputs. This is a common method in classification and regression tasks, like spam detection or house price prediction [11]. In contrast, unsupervised learning works with unlabeled data and aims to uncover hidden structures or patterns in data. Two popular applications of unsupervised learning techniques are clustering and association analysis. Reinforcement learning is more dynamic and the agent learns by interacting with an environment and receiving a reward/punishment at the end of each interaction, making it well suited to decision making applications like robotics and autonomous systems [12].

One of the most powerful areas of machine learning is deep learning, which has revolutionized the power of AI systems. Uses Artificial neural networks of multiple layers for modelling complex patterns in large datasets. Deep learning is especially powerful when it comes to processing unstructured data like images, audio, and text [13]. CNNs are frequently employed in image recognition and RNNs and Transformer models are widely used in tasks involving natural language processing and sequential data analysis. The applications of these models have been groundbreaking in areas like computer vision, speech recognition, and language translation [14].

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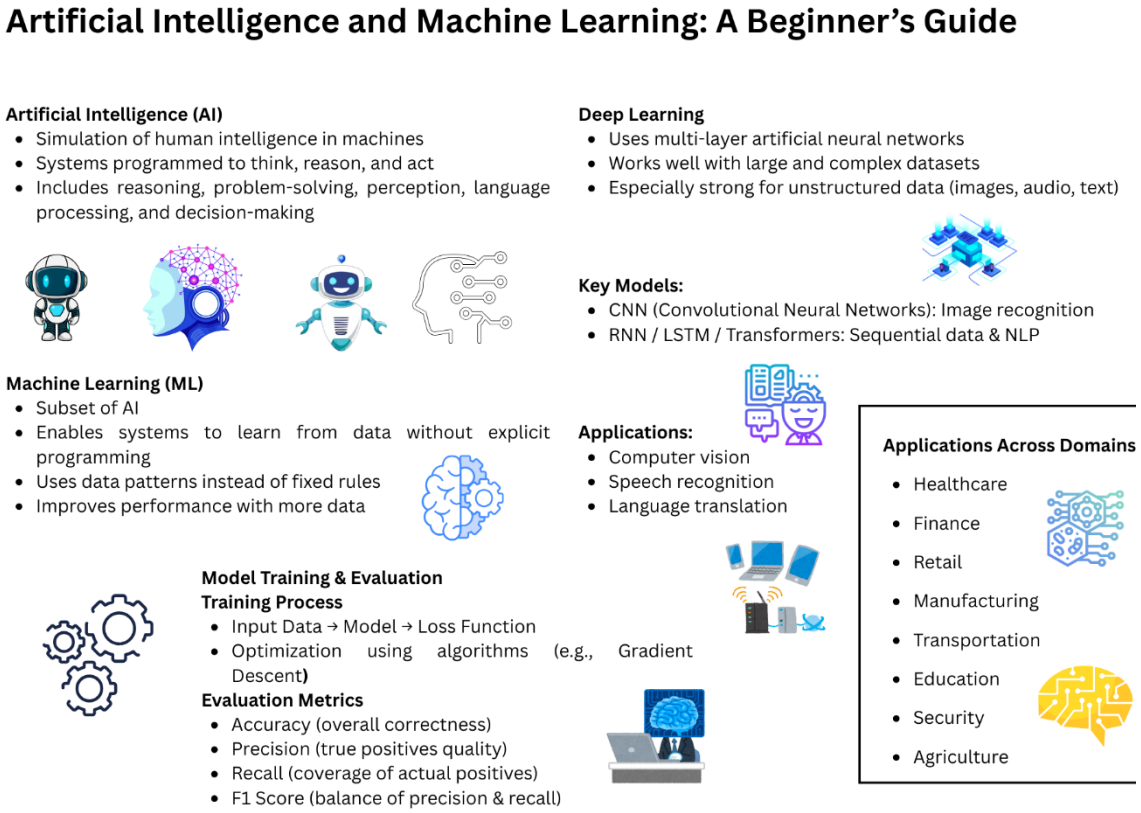

Figure 1. Artificial Intelligence and Machine Learning: A Beginner's Guide

Data analytics lifecycle is another crucial part of AI and ML foundations, and involves data preprocessing, feature extraction, model training, evaluation, and deployment. Good data is the basis for good models, and there are preprocessing techniques, like normalization, cleaning, and transformation, that will help to get the models to perform more effectively [15]. Feature engineering aids in identifying and creating meaningful features for improved prediction.

Further, optimization algorithms and loss functions are key to the training of machine learning models. Methods like gradient descent are applied to reduce errors and enhance the accuracy of the model. Different evaluation metrics such as accuracy, precision, recall and F1-score can be used to evaluate the effectiveness of the models in various scenarios [16].

NEXT-GENERATION INTELLIGENT DATA ANALYTICS

The next generation of smart data analytics is a highly automated, adaptive and artificial intelligence (AI) driven system designed to process large, disparate and live data streams. Unlike traditional analytics that are mainly history dependent and static in nature, next generation analytics are powered by AI and ML to provide predictive, prescriptive and even autonomous decision-making capabilities [17]. The transformation is largely due to the development of the "big data" field, of "cloud" and "edge" computing, and of various intelligent algorithms that cooperate to provide faster, more

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accurate and scalable analytics solutions [18].

One of the lynchpin components of the next generation of analytics is big data. Today, many volumes of data, high velocity streams and high variety datasets have to be handled efficiently. Structured, semi-structured, and unstructured data such as logs, images, videos, and sensor data are used to derive meaningful patterns using AI and ML algorithms [19]. Digital maturity and institutional readiness are also important to support the implementation of effective data-driven decision systems, especially in private and public complex infrastructures [20]. With distributed computing frameworks such as Hadoop and Spark, organizations can efficiently handle large-scale datasets, gaining real-time insights and improving decision-making processes [21].

Another key element of intelligent analytics systems is real-time and streaming analytics. In industries like finance, healthcare, and cybersecurity, where data is generated constantly, it is essential to process the data immediately [22]. Streaming analytics systems process data as it flows from data sources to identify anomalies, trends and events in real time. By combining machine learning with streaming, predictive and responsive functions are greatly improved so that real-time fraud detection, patient monitoring, and cyber threat identification can be achieved [23].

Also, edge and cloud-based AI systems fuel next-generation analytics. Cloud computing offers scalable storage solutions and powerful computing capabilities needed to train complex AI models, and edge computing brings computation closer to the data sources [24]. The combination of these features helps to decrease latency, increase efficiency, and ensure data privacy by processing sensitive information locally. These distributed systems of intelligence are especially useful in critical areas where quick decision-making is vital.

In today's analytics systems, Explicable AI (XAI) has become a must-have. The increased complexity of AI models can sometimes make their decision-making process opaque. The goal of XAI methods is to make AI predictions more interpretable and easier for humans to understand, particularly in high-stakes industries like healthcare and finance [25]. AutoML (Automated Machine Learning) and self-learning systems further enhance the capabilities of next-generation analytics. AutoML automates the process of feature engineering, model selection and hyper parameter tuning, making AI systems more accessible. Self-learning systems evolve over time, continually learning from incoming data, to create adaptive intelligence that continues to learn over time without frequent human interaction [26].

In this context, the readiness of governance and institutional accountability have been identified as key factors to ensure the responsible and effective deployment of intelligent analytics systems [27]. Intelligent data analytics is the next generation of data analytics, it's all about Big Data processing, Real Time Analytics, Edge and Cloud Computing, Explain ability and Automation. Such

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advancements are driving change in industries, with the potential for quicker insights, more precise decisions, and self-governing operations in ever-more complex and information-intensive settings [28].

CROSS-DOMAIN APPLICATIONS

The potential of cross-domain applications of Artificial Intelligence (AI) and Machine Learning (ML) in the field of intelligent data analytics illustrates the transformative impact of AI and ML across various critical sectors, empowering data-driven decision-making, automation, and predictive capabilities [28]. While the domains are distinct with their own set of features and issues, all of them have seen substantial gains from utilizing AI-infused analytics to improve effectiveness, accuracy, and promptness. Each of these domains possesses its own set of characteristics and challenges, but they all gain vastly from the use of AI-driven analytics, which can help enhance effectiveness, accuracy, and timeliness [29].

Healthcare Systems: In healthcare, AI and ML are revolutionizing the way medical data is analyzed and utilized for patient care. By analyzing vast amounts of clinical data, imaging information, and genetic information, intelligent data analytics can help facilitate early detection, diagnosis assistance, and personalized treatment plans [30]. Medical image analysis can involve using machine learning models to recognize patterns in medical images, like MRIs, CT scans, and X-rays, which can help physicians detect health problems, such as cancer, tumors, and neurological disorders, earlier. Predictive analytics also has significant value in predicting patient outcomes, hospital re-admissions and disease outbreaks [31]. In addition, AI-driven health monitoring devices and wearable's capture real-time patient data, which AI systems then leverage to make proactive healthcare decisions. But issues like data privacy, interoperability of healthcare systems, and the need for highly accurate and explainable models are still major concerns [32].

Cybersecurity Systems: AI-powered intelligent data analytics has become indispensable in the field of cybersecurity, given the growing complexity of cyber threats. Intrusion Detection, Malware Classification, Anomaly Detection in network traffic are some common use cases of machine learning algorithms. These systems can sift through vast amounts of security data and detect suspicious activity patterns that might signify phishing, ransomware, or even DDoS attacks [33]. Behavioral analytics also boosts security by tracking user activity and identifying abnormal behavior. But one of the significant obstacles of adversarial machine learning is when the adversary tries to trick the AI by providing false information. It is therefore very important to ensure the robustness, adaptability and responsiveness of cybersecurity systems in this domain in real time [34].

Blockchain Systems: AI and ML play a role in enhancing security, efficiency, and scalability in

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blockchain environments. Intelligent analytics can detect fraudulent transactions, suspicious activities, and anomalies within decentralized networks. Machine learning models are also employed to fine-tune smart contracts for efficiency and to guarantee their proper functioning [35]. Furthermore, by examining blockchain network dynamics and forecasting potential congestion, AI can help optimize consensus mechanisms and boost the overall performance of the network. While blockchain systems offer these benefits, they also come with challenges, including high computational expenses, energy usage, and scalability issues, that need to be overcome for blockchain and AI systems to be fully integrated [36].

Supply Chain Systems: AI-powered intelligent analytics has revolutionized supply chain management, especially in predicting demand, optimizing inventory, and planning logistics. These machine learning models process past sales data, market trends, weather conditions, and other external elements to make accurate sales predictions [37]. This allows organizations to minimize waste, optimize stocks and delivery efficiency. AI systems can also boost the visibility of the supply chain, as they will monitor the movement of goods in real time and alert the buyer if there are any potential issues in the transportation or production phases [38].

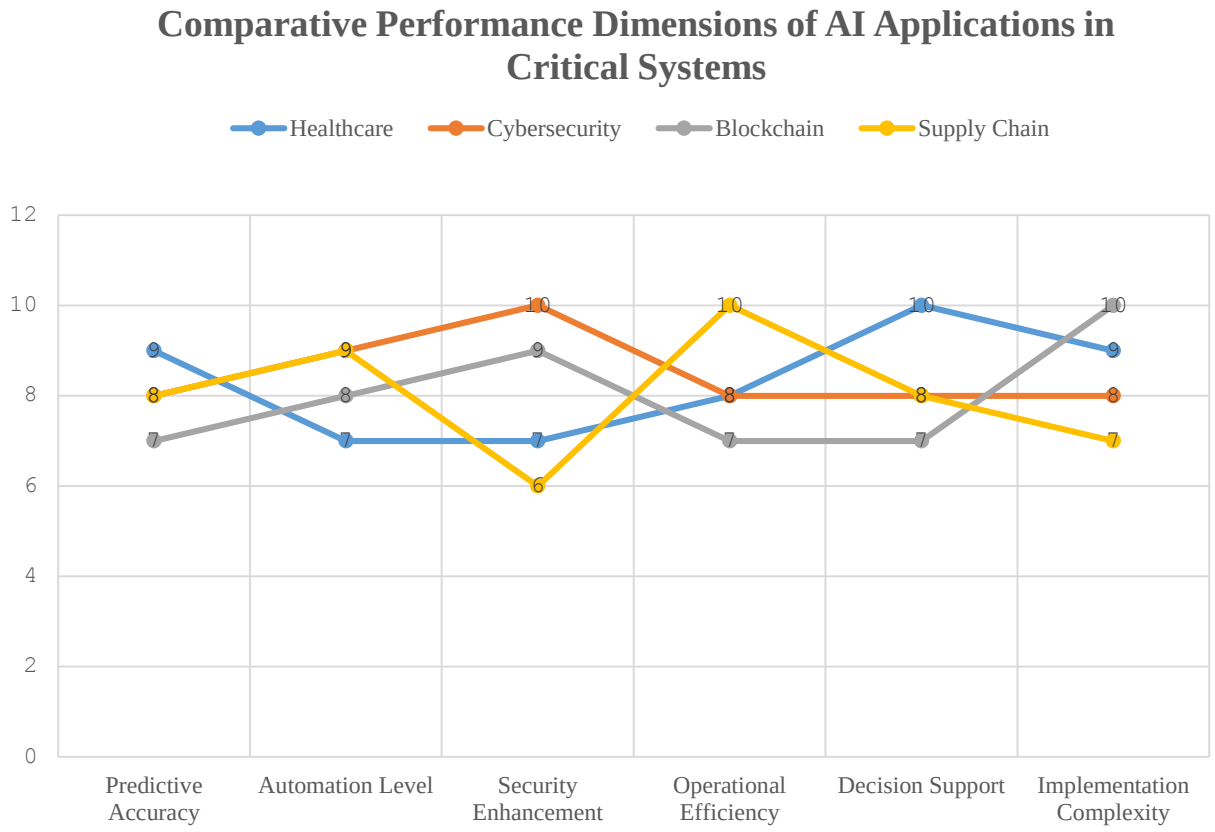

Figure 2. Comparative Performance Dimensions of AI Applications in Critical Systems

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Cross-Domain Applications: Intelligent Data Analytics with AI and ML is a valuable tool that can help solve complex problems in various industries. The requirements and constraints vary from one domain to another, but the overall aim is the same: making decisions based on the data and deriving actionable insights from it. The impacts of AI in the healthcare, cybersecurity, blockchain and supply chain sectors are just some examples of how AI can be a driver for creating smarter, more efficient, and more resilient systems [39].

CHALLENGES AND LIMITATIONS

While Artificial Intelligence (AI) and Machine Learning (ML) have made significant strides and are increasingly used for intelligent data analytics, there are still challenges and limitations to be addressed. The issues involve technical, ethical, operational, and organizational aspects, particularly in sectors like health care, cybersecurity, blockchain, and supply chain management [40]. These constraints are key to the creation of more robust, trustworthy and scalable intelligent systems.

Data quality and availability is one of the most pressing challenges. AI and ML models are heavily dependent on large volumes of high-quality data for training and validation. In practice, however, data is not always complete, consistent, or noise-free and may be biased. For instance, in a healthcare context, patient records could be stored in various hospitals and in non-compatible formats, making integration challenging [41]. In cybersecurity, the same is true: there is often limited and imbalanced attack information, impacting the reliability of models in identifying attacks. Improper data quality directly affects the performance and reliability of the models, resulting in incorrect predictions and a diminished confidence in AI systems [42].

The other significant barrier is interpretability and transparency of models. Many sophisticated machine learning methods, especially deep learning models, are "black boxes" and are difficult to comprehend how their decisions are made. Such lack of explain ability is a significant issue in critical domains like medical diagnosis, financial fraud detection, or other applications where stakeholders need to explain and trust the automated decisions [43]. Various techniques for Explainable AI (XAI) are being developed, although balancing the accuracy of the model with the level of interpretability is still a challenge.

Computational complexity and scalability are significant challenges as well. AI models are large and complex, and their training and deployment demand significant computational power, such as high-performance GPUs, distributed computing systems, and cloud resources. With the ever-growing data volume and complexity, scaling such models efficiently is becoming increasingly challenging [44]. Applications with real-time processing, like automatic cybersecurity systems or supply chain optimization platforms, place additional demands on the system and further boost operational costs

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due to the need to process data with a low latency [45].

There are other major constraints, namely ethical and privacy issues. AI systems frequently utilize personal and organizational information that is sensitive, which can lead to concerns regarding data protection, consent, and misuse. In healthcare, patient confidentiality is paramount and in cybersecurity and blockchain systems, data integrity and secure handling are crucial [46]. Furthermore, if training data is not representative of all populations, algorithmic bias can result in inequitable outcomes. This may lead to discriminatory practice in accessing employment, financing, and medical services or treatment recommendations, among other things, and is why it is important to build AI in an ethical way [47].

Another practical issue is integration with the current infrastructure. Numerous organisations run on legacy systems that aren't well equipped to handle AI-based analytics. Connecting modern AI solutions with these legacy systems can be a complicated, expensive and time-consuming process. Data silos, out-of-alignment architectures, and technical skill are additional obstacles to deployment [48]. For organizations to truly realize the potential of AI, they often need to go through a substantial digital transformation.

Finally, there are security issues with AI systems. There are various types of adversarial attacks that can affect machine learning models, such as data poisoning and model inversion techniques. In blockchain applications or cybersecurity, these risks are particularly important since the integrity of the system is crucial. AI and ML provide strong tools for intelligent data analytics, yet moving forward, significant problems such as data quality, interpretability, scalability, ethics, integration and security must be overcame if AI and ML are to be safely and effectively implemented in business fields [49].

KEY TRENDS AND FUTURE PROSPECTS

Artificial Intelligence (AI) and Machine Learning (ML) in the domain of intelligent data analytics is a dynamic field, constantly evolving and presenting new opportunities for automation, decision making and integration across domains. Emerging trends are not only enhancing the performance and efficiency of analytical systems but also tackling important barriers like privacy, scalability, interpretability, and adaptability [50]. The applications of intelligent data analytics will be very autonomous, decentralized and tightly connected to various industries including healthcare, cyber security, blockchain, and supply chain systems.

Federated Learning and Privacy-Preserving AI are among the most promising future trends. In the context of federated learning, machine learning models are trained on various decentralized devices or organizations, without transferring the raw data to a central server. This can improve data privacy

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and security, while at the same time allowing for collaborative model training [51]. It is particularly useful in the healthcare and financial sectors, where the sharing of sensitive data is constrained by regulations. The integration of federated learning with additional techniques like differential privacy and homomorphic encryption promises to establish it as a fundamental element of secure AI systems [52].

A newer research area is Quantum Machine Learning (QML), the combination of quantum computing and machine learning algorithms. Quantum computing could also be able to solve optimization problems that are too costly for classical computers, and train large-scale AI models more quickly than they can be trained today [53]. While it's still a fledgling technology, QML has the potential to transform industries such as drug discovery, financial modeling, and cryptographic security in the years to come.

The Autonomous Intelligent Systems are also emerging. The systems are engineered to function in an autonomous manner, relying on real-time data and adaptive learning mechanisms for decision-making. These include applications such as driverless cars, autonomous drones, intelligent robotics, and automated industrial systems. These systems typically involve reinforcement learning and real-time analytics to optimize their performance in dynamic environments [54].

AI powered Digital Twins are another game-changing trend. A digital twin is the virtual representation of a physical system that is continually updated with real-time data. Digital twins can leverage AI and ML to simulate, predict and optimise complex systems, like manufacturing plants, smart cities or even healthcare systems [55]. This allows organizations to simulate scenarios, anticipate failures, and optimize operations without impacting the actual systems.

It is also anticipated that cross domain integration of intelligent analytics will be an important part of the future. AI systems will be more interdependent and share knowledge and information between industries. One such example is that by implementing healthcare analytics into supply chain systems, you can enhance vaccine distribution, and integrating cybersecurity intelligence with blockchain systems can help bolster transaction security [56]. This networked world will bring about more comprehensive and intelligent decision making processes.

Also, the development of next-generation Explainable & Trustworthy AI will be pivotal. The challenge of ensuring AI systems are transparent, fair, and accountable will be crucial to building trust and regulatory adherence as AI becomes more autonomous [57]. Future AI models will be able to not only predict but also explain the rationale behind their predictions, enhancing their ability to be used in high-stakes environments.AI models of the future will make predictions, but also give a clear reason as to why they made those predictions, which is better for high-stakes applications [58].

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Volume 2, Number 3, 2026
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The trajectory of AI and ML in intelligent data analytics is marked by enhanced decentralization, automation, and intelligence. The use of emerging technologies like federated learning, quantum computing, digital twins, and autonomous systems will mark a change in data analysis and utilization [59]. All these developments will allow for more intelligent, faster and safer decision-making in all the key sectors of industry, and lead to a more intelligent digital ecosystem.

CONCLUSION

Artificial Intelligence (AI) and Machine Learning (ML) have significantly changed the way that intelligent data analytics are performed, shifting from descriptive to predictive, prescriptive and autonomous data analytics. This review has covered the basics, the future, the cross domains, the key challenges, and the future directions of AI and ML in intelligent data analytics, especially in healthcare, cyber security, blockchain and supply chain systems. Overall, these technologies are not just improving the speed and efficiency of analysis but are also changing the way industries function and make important decisions.

The core principles of AI and ML are the building blocks of AI-integrated systems. With the use of techniques like supervised learning, unsupervised learning, reinforcement learning, and deep learning architectures, machines are able to handle large and complex datasets. These will be complemented by an integrated data analytics lifecycle so that data can be turned into insights. Optimization algorithms and evaluation metrics are also used to ensure that models have high accuracy and reliability, making them suitable for real-world applications.

Next-generation intelligent data analytics is a more sophisticated environment that integrates the use of big data processing, real-time analysis, edge computing, cloud integration and explainable AI to provide more swift and explainable insights. By combining AutoML and self-learning systems, human involvement is minimised and models can be continually improved. In sectors where instant decision-making and adaptable intelligence are vital, like healthcare monitoring systems, cybersecurity defense platforms, and logistics optimization networks, these advancements play a crucial role.

The versatility and impact of AI-driven analytics are showcased in cross-domain applications. In the healthcare industry, AI contributes to more precise diagnoses, predictive treatment, and patient monitoring, which leads to better patient health and improved efficiency. In the field of cybersecurity, ML algorithms can be employed to identify anomalies, block intrusions, and enhance digital security measures against evolving cyber threats. AI technologies are crucial for their blockchain systems, supporting fraud detection, smart contract optimization, and enhanced security mechanisms; and their supply chain systems rely on predictive analytics for demand forecasting, inventory management,

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and disruption mitigation. From telecom to retail, and from healthcare to manufacturing, these are examples of applications where intelligent analytics can make a difference in making systems more efficient, more accurate, and more resilient.

While such progress has been made, there are other obstacles to be overcome. There remains a need for data quality, privacy, interpretability and scalability that continues to hamper broad adoption. There are ethical issues that come with biases and fairness in algorithmic decisions, which pose questions of accountability and trust. Further, there are substantial technical and operational challenges related to the implementation of AI systems into existing systems and the risk of adversarial attacks. To guarantee safe, reliable and responsible use of AI technologies, it is crucial to address these challenges.

In the future, AI-driven digital twins, federated learning, quantum machine learning, and autonomous systems will shape the future of intelligent data analytics. Such innovations will contribute to increased system intelligence, computational efficiency, and privacy, and to more interwoven and adaptive digital ecosystems. As AI becomes more explainable and trustworthy, customers will be even more at ease and compliant with regulations, especially in critical sectors.

In conclusion, AI and ML are driving a paradigm shift in intelligent data analytics by enabling smarter, faster, and more autonomous systems. While challenges remain, continuous research and technological advancements are paving the way for more secure, scalable, and ethical AI solutions. The potential of intelligent data analytics is the ability to interoperate them in different sectors and reach a more intelligent, efficient and interconnected global digital infrastructure in the future.

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