**Advancements and Challenges in Health Informatics: A Comprehensive Overview of Data Management, Interoperability, AI Applications, and Privacy Concerns**

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1. **INTRODUCTION**

Healthcare constitutes a multifaceted and data-rich procedure wherein information related to the well-being and medical status of individual patients is retained and employed for clinical treatment and administration (Donabedian *et al*., 1966). The assessment of intricate applications in medical informatics encompasses not just the information system itself, but also its influence on the organizational setting within which it is put into practice (Anderson *et al*., 2002). Bioinformatics seeks to explore and comprehend biological processes at the molecular level, enabling the formulation of novel hypotheses (Venter *et al*., 2001; Lander *et al*., 2001). Progress in biotechnology has further attention toward the prognosis, diagnosis, and treatment of diseases through gene and protein analysis (Pastur-Romay *et al*., 2016). Moreover, this data is pooled for supplementary objectives, including the oversight of local health services, disease tracking and surveillance, and the strategic planning of health service provision on regional, national, and global scales. Within healthcare institutions, services, and frameworks, substantial quantities of data are amassed, stored, examined, transferred, and accessed routinely (Donabedian *et al*., 1966).

Health informatics has revolved around crafting information systems tailored for medical and healthcare applications (Haux *et al*., 2006). Progressions and breakthroughs in health informatics also have the potential to enhance the structuring and control of information, benefiting healthcare and information experts, health service administrators and strategists, as well as patients and the common people. As such, there is a conceptual overlap with health information management. For instance, the creation of online portals for patients to access health-related information has implications for how individuals obtain and handle health-related information (Moen *et al*., 2005). Alongside individual patient data, current insights on disease prevention, diagnosis, treatment, and management from research are being disseminated and are essential for healthcare professionals in furnishing effective and secure patient and public care. Information management tactics can be employed to mitigate issues linked to the utilization of information systems within the healthcare domain (Haux *et al*., 2006).

1. **HEALTH INFORMATION SYSTEMS**

**Electronic Health Records (EHR) and Electronic Medical Records (EMR)**

The Electronic Health Record (EHR) is commonly understood as the compilation of electronic health information pertaining to patients, often in the form of electronic medical records (EMRs). EMRs, primarily sourced from healthcare providers within medical institutions, can serve as a data reservoir for constructing EHRs (Shi *et al*., 2020; Ebadollahi *et al*., 2006). Over the past few decades, EHRs have been integrated into nearly all healthcare systems in the United States. EHRs were designed to assist with administrative functions such as registration, scheduling, billing and fundamental clinical care, rather than research endeavors. EHRs are gradually being reimagined to better accommodate research objectives, and novel approaches are being devised to surmount existing limitations. The use of EHRs for research presents an exciting domain characterized by ongoing progress in response to ever-evolving data, showcasing remarkable potential (Kim *et al*., 2019).

The process of digitalizing healthcare services commenced with the conversion of traditional paper-based health and medical data into electronic medical/health records, eliminating the need for physical documents (Stead *et al*., 2005). As per the International Organization for Standardization, an EHR refers to a secure repository of patient data in digital form, ensuring secure storage and exchange accessible to authorized users. It encompasses historical, current, and future-oriented information, primarily aiming to support ongoing, efficient, and high-quality integrated healthcare (ISO, 2015). Theoretically, clinicians are expected to inquire about a patient's medical history, assess current medication usage, and evaluate emotional well-being, subsequently recording all this information within the Electronic Health Record (EHR) system.

EMRs can be categorized as follows:

1. **Integration of Computer Systems:** This involves combining computer systems across various departments, functions, and systems within a hospital. This includes outpatient/inpatient care, emergency, physician, nursing information system, ICU system, examination/checkups information system, and pharmacy information system.
2. **Support for Organizational Activities:** EMRs support a range of organizational activities within a hospital, such as clinical diagnosis, medical education, medical research, and operation/management.
3. **Diverse Data Formats:** EMRs are capable of storing data in various formats, including text, figures, videos, and audios.
4. **Embedding Medical Standards and Guidelines:** EMRs embed necessary medical documentation standards and clinical guidelines to assist medical professionals while recording data into the system (Chang *et al*., 2012).

EMRs primarily generate static medical data, considering patients as recipients of care. In contrast, EHRs have a more expansive scope, encompassing personal and social health activities. Integrating a social module through Web 2.0 into healthcare settings builds upon an open access model, mutual trust, support for common goals, health promotion through collaboration, and enhanced healthcare via conversations and information sharing. This approach empowers customers (patients) by enabling them to generate dynamic health information.

**Health Information Exchange (HIE) and interoperability challenges.**

Over the past decade, the proliferation of Health Information Exchanges (HIEs) has been evident. HIE involves the electronic transmission of health information between healthcare organizations, adhering to nationally recognized standards (Dupont *et al*., 2023). Among the studies, those based on multi-hospital data exhibited slightly more net positive effects of HIEs compared to single-hospital studies. Two studies specifically validated the actual usage of HIE during admission—rather than merely acknowledging the presence of HIE capabilities. These studies both indicated noteworthy reductions in unplanned readmissions when HIE was both available and utilized (Vest *et al*., 2019). Notably, these studies didn't quantify the extent of HIE utilization; they solely categorized it as a binary variable, denoting whether practitioners had accessed the HIE software.

**Personal Health Records (PHR) and patient engagement**

The PHR is precisely defined as an electronic application that grants individuals the ability to access, manage, and share their health information, along with authorized information for others, all within a secure, private, and confidential environment (Tang *et al*., 2006). It emerged as a captivating and advancing technology, gaining traction across various countries (SooHoo *et al*., 2022). A Patient Portal (PP), alternatively referred to as a PHR, is a patient-managed platform containing health information. In the USA, it was projected that PHR adoption would surpass 75% by 2020. However, the primary impediment to the broader utilization of PHR functionality is the healthcare providers' ability to assist and implement such features for the benefit of patients (Ford *et al*., 2016).

A PHR holds the potential to enhance health outcomes and offer more precise data in hospital EMR systems (Archer *et al*., 2011). Realizing these advantages necessitates patients' ease of PHR utilization and comprehension of the enclosed data. Healthcare providers must ensure data accuracy, address legal considerations, and promptly respond to patient queries (Lester *et al*., 2016). Furthermore, a systematic review evaluated the obstacles to wider PHR adoption from the patient's perspective and identified perceived usefulness, concerns about privacy and security, and internet access as the main barriers (Abd-Alrazaq *et al*., 2019). To delve further, PHR systems are information systems that integrate data, tools, and functionalities tailored to individual health. PHR is an electronic application that empowers individuals to securely, privately, and confidentially access, manage, and share their health information and that of authorized individuals (Foundation *et al*., 2003).

The advent of novel technologies results in a surge of data, necessitating integration into PHRs to offer a comprehensive and precise portrayal of patient health. The scope of PHRs should broaden to encompass capabilities extending beyond hospital data. For this evolution to transpire, hospitals must enhance their data capturing, compilation, and dissemination practices. This involves updating existing technical and administrative processes, facilitating a seamless transition toward a more impactful and efficient PHR. Collaborative efforts among stakeholders, including regulatory bodies, care providers, funders, and patient representatives, are indispensable to align strategies, overcome challenges, and facilitate successful integration (Alanazi *et al*., 2023).

1. **CLINICAL DECISION SUPPORT SYSTEMS (CDSS):**

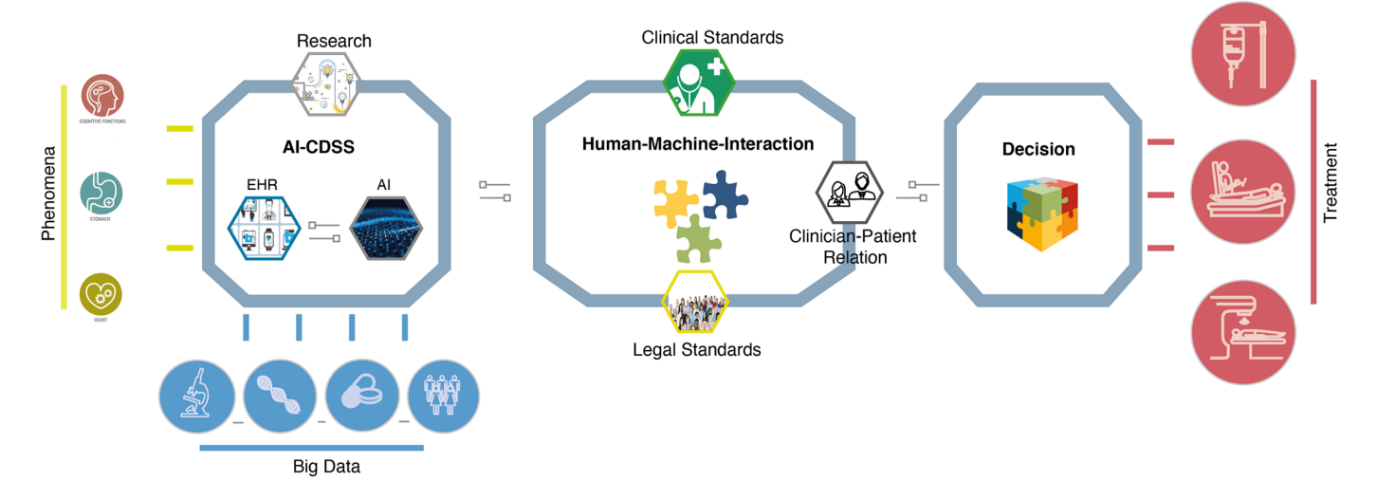
**Principles and benefits of CDSS.**

The trust and utilization of CDSS were influenced by the recommendations of other General Practitioners (GPs) or practices that found them valuable. The reliability of CDSS sources aligning with those esteemed as credible or scientifically trustworthy by GPs was essential, and this origin of CDSS information should be easily accessible to GPs. Furthermore, the accuracy of CDSSs was particularly appreciated, especially when supported by rigorous validation studies that considered the broader patient context. CDSS interventions have significantly contributed to enhancing medical decision-making (Wang *et al*., 2021). A healthcare IT system has been developed to gather inputs from diverse clinical sources, aiming to offer clinicians decision-making assistance. It's described as an active knowledge system employing various patient data elements to generate tailored advice for specific cases. The foundational principles for a CDSS with a primary focus on medical images, as highlighted the following key aspects:

1. **Multidisciplinary Clinical Knowledge System:** Rather than being merely an information technology tool, a CDSS should be recognized as a comprehensive clinical knowledge system involving multiple disciplines.
2. **Clear, Evidence-Based Recommendations:** The system's recommendations must be crystal clear, concise, unambiguous, and firmly grounded in evidence. This evidence should be current, drawn from diverse sources, and the strength of its foundation should be transparent.
3. **Seamless Workflow Integration:** The CDSS should seamlessly integrate into existing workflows, offering enhanced efficiency for healthcare providers, patients, and payers alike.
4. **Targeting Clinical Performance Gaps:** The initiative should strategically address well-defined gaps in clinical performance, seeking to improve outcomes in these areas.
5. **Workflow Enhancement:** The CDSS should not only address clinical aspects but also contribute to optimizing workflows, in line with the insights provided by Parmar *et al*. [2015].

**Artificial Intelligence - CDSS**

An alternative kind of CDSS exists, which diverges from the traditional knowledge-based approach. Instead, it relies on Artificial Intelligence/Machine Learning (AI/ML) to learn from historical experiences and discern patterns within clinical data. This eliminates the necessity for crafting rules or incorporating expert input. Such a system is often referred to as an AI-based CDSS (AI-CDSS). AI's capacity to improve the accuracy and appropriateness of Clinical Decision Support Systems (CDSS) has generated considerable attention among doctors. This has led to the broadening of its potential uses across various domains of modern healthcare, ranging from pharmacogenetics to matters concerning public health (Fleming *et al*., 2018; Cvetkovic *et al*., 2016). In order to generate suggestions, AI-CDSS needs detailed information from the EHR system. The problem is that these rural clinics are also experiencing shortage of medical staff, especially nurses, who usually perform initial check-ups such as checking blood pressure, recording the medical history, and taking the patient’s temperature, etc.



**FIGURE 1** Clinical decision-making with AI-CDSS focuses on the design of AI-CDSS and related data generation and data analysis, is characterized by human–machine-interaction, and finally aims at the management of the outcome of the decision on the treatment of patients (Bleher *et al*., 2022).

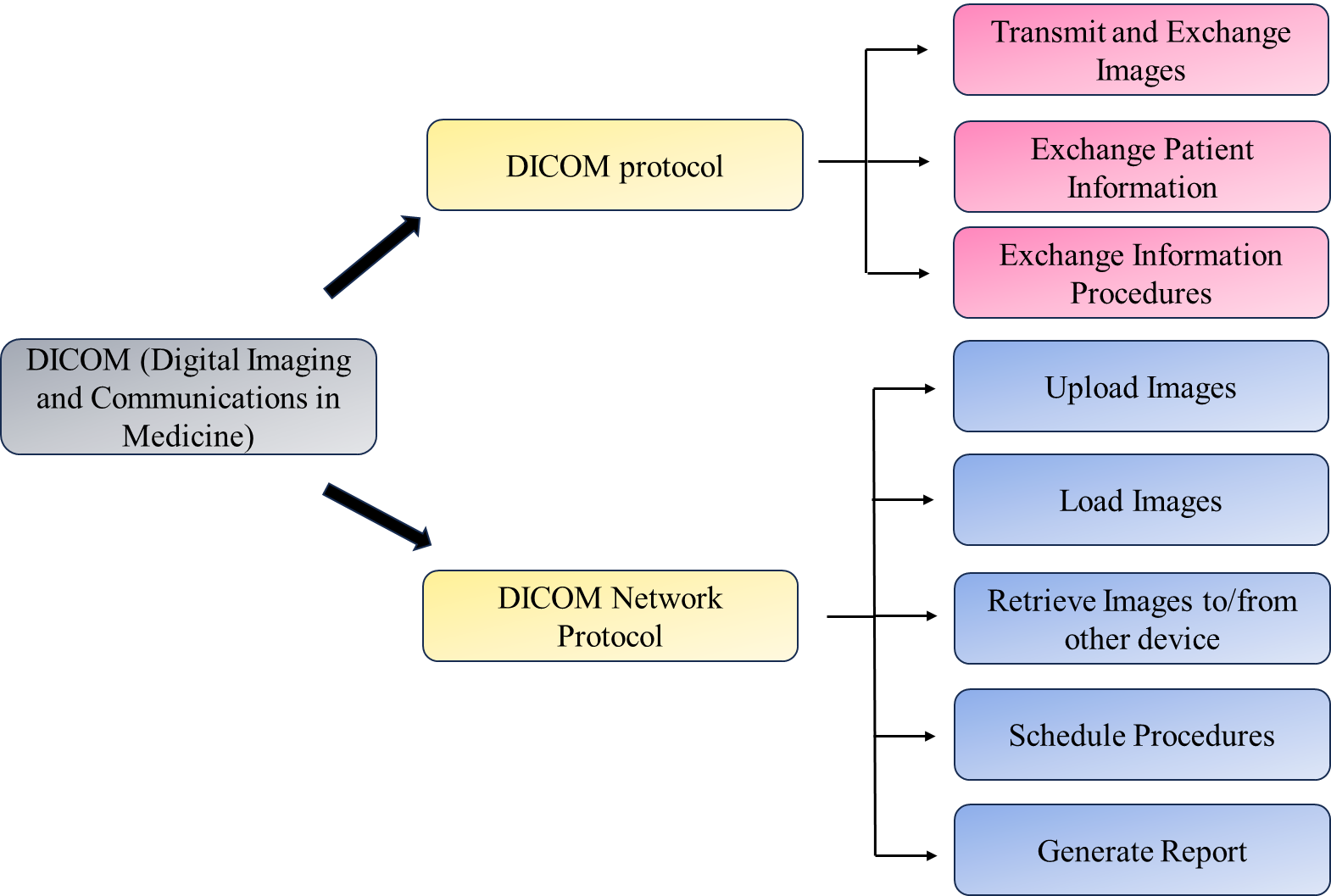
The developers of the AI-CDSS system initially followed a conventional workflow approach, assuming that clinicians would allocate sufficient time for each step. It's worth noting that we don't hold an algorithm with greater accuracy in this regard. Nevertheless, we strongly advocate for the collaboration of machine learning and AI researchers to collectively participate in the design and development of AI-CDSS, adopting a socio-technical perspective (Bleher *et al*., 2022).

1. **HEALTH INFORMATICS STANDARDS AND INTEROPERABILITY:**

**HL7, DICOM, and other healthcare data standards.**

This section highlights the key interoperability standards in healthcare, focusing on Health Level 7 (HL7), its derivative standard Fast Healthcare Interoperability Resources (FHIR), Digital Imaging and Communications in Medicine (DICOM), and JavaScript Object Notation (JSON). Each standard is examined, and its primary attributes are underscored. HL7 serves as a widely adopted standard for facilitating the exchange of healthcare information. FHIR, a more contemporary and adaptable standard, has evolved from HL7, enhancing its capabilities. JSON, a lightweight data-interchange format, finds common use in web applications. HL7 is a comprehensive suite of international standards governing the exchange, integration, sharing, and retrieval of electronic health information. These standards outline the structural foundation, messaging formats, and protocols essential for promoting interoperability among healthcare IT systems within organizations and across them. It's important to note that the HL7 format specifically pertains to HL7 Version 2 (Schweitzer *et al*., 2022).

This particular standard serves the purpose of storing, transmitting, and displaying digital medical images, including X-rays, MRIs, and ultrasound images. It's structured into two primary components: the file format, utilized for transmitting and exchanging images (Blazona *et al*., 2007). DICOM network protocol, which permits the display and storage of digital medical images in various formats like X-rays, MRIs, and ultrasound images. These two components function in tandem, ensuring that images adhere to a standardized format and their exchange follows a standardized process (Indrajit *et al*., 2007). The alignment of DICOM capabilities across different vendors holds significant importance. This alignment bolsters interoperability within the healthcare domain and drives advancements in medical imaging (Channin *et al*., 2001). In the realm of medical imaging, numerous endeavors have been undertaken to establish a platform for exchanging DICOM samples. However, these efforts have not satisfactorily addressed the three-fold equilibrium encompassing economics, openness, and confidentiality (Nichols *et al*., 2023).



**FIGURE 2** Redrawn the block diagram of the DICOM standard (Ait Abdelouahid *et al*., 2023).

**Interoperability in IoT**

Semantic interoperability involves the automated or semi-automated interpretation of communicated information between different applications to ascertain equivalent meanings (Asuncion, 2010). The presence of semantic heterogeneity poses a significant challenge to achieving interoperability, as numerous systems lack clear descriptions of the semantics associated with the shared information. These data streams are subsequently directed through gateways to the cloud for subsequent processing (Al-Fuqaha *et al*., 2015). Heterogeneity in devices can manifest in terms of their capabilities, features, vendors, and specific application requirements (de Mello *et al*., 2022). This diverse and heterogeneous nature of IoT systems poses challenges in effectively and efficiently utilizing device services. This characteristic significantly impedes the further advancement of IoT. Interoperability emerges as a potential solution to attain uniformity amidst this heterogeneity. It operates across various levels, encompassing technical, syntactic, and semantic dimensions (Rahman *et al*., 2020), offering the potential to address these challenges and foster the development of IoT systems.

1. **MOBILE HEALTH (MHEALTH) AND WEARABLE DEVICES:**

The growing prominence of mHealth is attributed to various factors, including consumer preferences, shifts in healthcare policies, and technological innovations. Among these advancements, wearable health devices stand out as a promising avenue for improving care. These devices, often integrated into accessories like watches or clothing or applied as skin patches, primarily capture continuous data. They are commonly paired with other devices, such as smartphones, to gather, interpret, and transmit data (DeVore *et al*., 2019).

**Role of mobile apps and wearables in healthcare.**

In 2022, smartphone usage had exceeded 80% of the global population, with over 60% having access to the Internet. Among the array of mHealth services, mobile apps emerged as particularly favoured. During the same year, the Google Play Store hosted more than 52,000 distinct healthcare and medical apps, while the Apple App Store featured over 51,000. Among the various mobile apps, those geared towards managing diet and physical activity are among the most popular digital health tools. These apps provide valuable support to users seeking to enhance their lifestyle and overall well-being (Statista, 2019; Hwang *et al*., 2021).

**Monitoring chronic conditions and wellness using mHealth.**

Chronic non-communicable diseases (NCDs) stand as the primary cause of global mortality, as highlighted by Benziger *et al*. (2016). These diseases collectively lead to over 40 million deaths annually. Among NCD-related fatalities, cardiovascular diseases, cancers, and respiratory illnesses constitute the majority, as reported by the World Health Organization (WHO, 2021). The roots of most NCDs can be traced back to modifiable behavioral risk factors (Heneghan *et al*., 2013). The Global Burden of Disease Study's findings underscore that dietary risk factors were responsible for around 8 million deaths in 2019 (Qiao *et al*., 2022). In terms of specific diseases, physical inactivity has been linked to 6% of global coronary heart disease cases, 7% of type 2 diabetes incidences, and 10% of breast cancer occurrences (Lee *et al*., 2012). Moreover, the economic ramifications of physical inactivity are substantial. Notably, it is accountable for a significant economic burden, encompassing healthcare system expenditures amounting to $53.8 billion USD and productivity losses totalling $13.7 billion USD (Ding *et al*., 2016). The significant worldwide burden posed by lifestyle-related non-communicable diseases (NCDs) has led to the implementation of numerous prevention programs (Gelius *et al*., 2020; Herforth *et al*., 2019). In 2004, the World Health Organization (WHO) embraced the "Global Strategy on Diet, Physical Activity and Health," which aimed to advocate for health preservation and enhancement through the promotion of healthy eating and physical activity. This global approach spurred the adoption of national policies related to physical activity and nutritious diets in various countries.

Among these strategies, school-based physical education and infrastructural policies have demonstrated notable efficacy in promoting physical activity (Gelius *et al*., 2020). Additionally, numerous countries have rolled out initiatives such as national food-based dietary guidelines, food system enhancements, agricultural policies, educational campaigns, and nutrition education programs. All of these endeavors have been developed to encourage and support healthier dietary habits among the populace (Herforth *et al*., 2019; Abril *et al*., 2019). The wearable form factor is gaining increasing significance for numerous patients when evaluating potential new wearable devices for acquisition. A growing array of functionalities are being incorporated into various everyday wearable devices, such as headphones and wristbands. Yet, an emerging trend within the realm of wearable devices involves the adoption of modular accessories, as observed by Blocks *et al*., (2018).

1. **ARTIFICIAL INTELLIGENCE (AI) IN HEALTHCARE:**

**Machine learning and deep learning applications.**

In recent years, DEEP learning has ushered in an exciting and transformative trend in the realm of machine learning. Its theoretical foundations are deeply rooted in the classical literature of neural networks (NN). Within modern medicine, automated medical imaging analysis holds paramount importance. DEEP learning presents the potential to automate and seamlessly integrate the extraction of pertinent features with the classification process (Nie *et al*., 2016; Xu *et al*., 2016). This technique also finds utility in processing hyperspectral images (Zhou *et al*., 2016), wherein spectral and spatial learned features are synergistically amalgamated in a hierarchical framework to characterize tissues or materials.

The intrinsic ability of DEEP learning to abstract vast, intricate, and unstructured data offers a potent approach for analyzing heterogeneous datasets like gene alleles, protein occurrences, and environmental factors. Its impact on the field of bioinformatics has been explored across several related domains (Leung *et al*., 2016; Angermueller *et al*., 2016), leading to substantial advancements, particularly in handling unstructured data prevalent in medical imaging, medical informatics, and bioinformatics. Predominantly, the application of DEEP learning to health informatics has thus far focused on processing health data obtained from unstructured sources.

**AI-driven diagnostics and treatment recommendations.**

Convolutional neural networks (CNNs) possess an innate capacity to acquire a hierarchical understanding of progressively intricate features, rendering them capable of directly processing image patches focused on anomalous tissues. CNNs have found notable applications in medical imaging, including tasks such as the classification of interstitial lung diseases based on computed tomography (CT) images (Anthimopoulos *et al*., 2016), tuberculosis manifestation classification using X-ray images (Cao *et al*., 2016), neural progenitor cell classification from somatic cell sources (Jiang *et al*., 2015), identification of hemorrhages in color fundus images (Van Grinsven *et al*., 2016), and anatomical classification of organs or body parts in CT images (Roth *et al*., 2015). While CNNs are primarily designed for 2-D images, MRI and CT segmentation tasks inherently involve 3-D data. The intricacy of this challenge is further compounded by the presence of anisotropic voxel sizes (Fritscher *et al*., 2016).

Yan *et al*. (2016) also introduced a body-part recognition system. Interpreting diagnostic information from images can be highly subjective. To mitigate this, computer-aided diagnosis (CAD) offers an objective evaluation of underlying disease processes. For diseases with progressive patterns, such as Alzheimer's, multiple sclerosis, and stroke, analyzing brain scans based on multimodal data and detailed brain region maps is essential. CAD encounters significant challenges, notably the diverse shapes and intensity variations of tumors or lesions, even within the same imaging modality. Moreover, the presence of Rician noise, nonisotropic resolution, and bias field effects in Magnetic Resonance Images (MRI) requires more sophisticated handling than simpler machine learning approaches offer. To navigate this complexity, manually engineered features are extracted, followed by training conventional machine learning methods to classify them in a separate phase (Ravì *et al*., 2016).

Choi *et al*. (2016) utilized Restricted Boltzmann Machines (RBMs) to learn activities from datasets obtained from smartwatches and home activities. Notably, their approach exhibited enhancements over baseline methods. Nonetheless, when employing deep learning techniques on low-power devices like smartwatches and sensor nodes, efficiency becomes a focal point, especially when dealing with deep learning models with substantial computational complexity. Wulsin *et al*. (2010) proposed a Deep Belief Network (DBN) methodology for anomaly detection in EEG waveforms. Electroencephalography (EEG) records brain electrical activity. The interpretation of brain activity waveforms is intricate due to the input signal's high dimensionality and limited comprehension of inherent brain processes. DBN also found application in detecting arrhythmias from electrocardiography (ECG) signals.

DBNs were also applied to monitor heart rhythm by utilizing ECG data, as demonstrated by Yan *et al*. (2015). The central objective of this system is the identification of arrhythmias, a challenge in complex pattern recognition. For wearable and implantable EEG sensors, where energy efficiency is crucial, Wang *et al*. (2015) devised a DBN-based approach to compress signals. This strategy resulted in over 50% energy savings while upholding accuracy for neural decoding. The advancement of AI technologies has redefined the roles of clinicians, ushering in new decision-making processes within medical contexts. Innovative AI-driven protocols have the potential to offer diagnostic and treatment decisions by scrutinizing intricate datasets, and introducing transformative changes to medical practice.

1. **CHALLENGES AND FUTURE TRENDS IN HEALTH INFORMATICS:**

The expanding realm of mHealth presents an arena for innovation and emerging trends in capturing patient health data, offering novel avenues to promote a healthy lifestyle. Noteworthy technology giants like Apple Inc., Google Inc., and Samsung Group have incorporated inventive strategies for health activity tracking into the design of their smartphones (Rosenberger *et al*., 2016; Marceglia *et al*., 2015). Health care providers and insurers can contribute to patient education aimed at self-protection. The OIG (Office of Inspector General) encourages healthcare providers to distribute its brochure, which offers guidance to patients on avoiding pitfalls related to medical identity theft (Taitsman *et al*., 2013). To manage this influx of data, companies like Validic, Human API, and Open mHealth facilitate the aggregation of cloud-based mHealth data for various analytical models. To fully unlock the potential of this data for enhancing health outcomes, these services should integrate with electronic medical record systems. This integration could also bring benefits to patient providers (Pennic *et al*., 2015; Prnewswire *et al*., 2016).

**Addressing interoperability challenges.**

However, establishing connections between geographically dispersed devices necessitates advances in research not only in terms of supporting diverse types of interoperability but also in addressing specific domain-related aspects within the IoT landscape. Given the widespread use of cloud applications and solutions, achieving interoperability in Cloud Computing can facilitate the transfer of solutions or data from one cloud provider (public or private) to another. An overarching challenge in cloud computing is the issue of "lock-in," where cloud consumers become reliant on specific provider services (such as data or applications) and face obstacles when attempting to transition to different providers or within the same cloud environment.

Interoperability within a Software Ecosystem (ECOS) pertains to the capacity of different Information Systems to seamlessly connect and share services in a dynamic manner. The interactions among these systems generate aggregated value for the ECOS, necessitating the opening of its boundaries to enable third-party applications to connect and utilize ecosystem services, thereby creating value for all stakeholders involved. In this context, the interoperability of Information Systems and their services becomes paramount. As a result, ensuring comprehensive interoperability stands as a pivotal concern (Maciel *et al*., 2017)

**Data security and patient privacy concerns.**

In recent years, advanced persistent threats have emerged as targeted attacks against information systems with the primary aim of illicitly extracting recoverable data by the attacker. Consequently, the invasion of patient privacy has become a growing concern within the realm of big data analytics. Organizations now face the challenge of addressing various interconnected and critical issues. Data security plays a central role in governing data access throughout its lifecycle, while data privacy aligns this access with privacy policies and regulations. These regulations determine who can access personal, financial, medical, or confidential information.

An incident highlighted in Forbes magazine serves as a warning signal for patient privacy concerns. The incident involved Target Corporation sending baby care coupons to an underage girl without her parents' knowledge. This occurrence underscores the need for big data analytics to incorporate privacy considerations, where developers should ensure that their applications adhere to privacy agreements. Sensitive information should be safeguarded regardless of changes in applications or privacy regulations. The privacy of medical data is a critical factor that demands careful attention. While big data presents boundless opportunities for advancing health research, knowledge discovery, clinical care, and personal health management, several challenges hinder its full potential in the healthcare domain. These challenges encompass technical complexities, privacy and security issues, and the availability of skilled talent. Notably, big data security and privacy pose significant barriers for researchers in this field (Hill *et al*., 2012).

**Conclusion**

The escalating threats of targeted attacks underscore the critical importance of safeguarding patient privacy in the realm of big data analytics. The incident involving unsolicited coupons serves as a poignant reminder of the need for vigilant privacy protection. While the potential of big data in healthcare is immense, obstacles such as technical intricacies, privacy concerns, and a skilled workforce shortage persist. Addressing these challenges is imperative to unlock the full benefits of big data while upholding patient privacy and data security.

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