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Applicability and Constraints of Implementing Artificial Intelligence in Biotechnology and Healthcare

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Abstract

The present project investigates the feasibility and limitations of implementing Artificial Intelligence (AI) in healthcare and biotechnology through a global analysis of use cases. The sudy aims to assess the practicality and viability of implementing AI solutions in these fields, examining their real-world impact on diagnostics, treatment, drug discovery, and patient care.

Key objectives involve identifying successful use cases demonstrating AI's positive contributions and elucidating potential barriers and ethical considerations. Utilizing a mixed-methods approach, the study employs an extensive survey and interview-based research methodology to gather insights from diverse stakeholders. The survey quantifies current adoption rates, perceived benefits, and challenges associated with AI integration. The majority of the population agrees that regulations are necessary to ensure responsible AI use. Interviews with experts further explore perspectives, highlighting AI's potential as a valuable tool for education and social institutions, generating skilled jobs, and enhancing social life. However, challenges such as the destruction of manual labor, the digital divide, and concerns about human attention spans and IQs are also noted.

This initiative underscores moral, ethical, and legal concerns while examining the potential of AI and Machine Learning (ML) in genomics, biotechnology, and healthcare. Recommendations include increasing public awareness, establishing organizations, and prioritizing user privacy. The initiative aims to ensure that research is conducted ethically and practically, understanding AI applications, gathering insights, and analyzing potential difficulties.

Introduction

Artificial Intelligence (AI) is a rapidly expanding field within computer science that strives to develop machines capable of executing cognitive tasks such as creativity, problem-solving, decision-making, and reasoning. Its foundations lie in a multidisciplinary approach, encompassing economics, probability, psychology, linguistics, philosophy, neuroscience, mathematics, search, and mathematical optimization. The origins of AI trace back to ancient philosophical inquiries into the potential of artificial beings, with significant advancements occurring since the 1700s, enabling the automation and control of human thought [Garg, 2021].

Categorically, AI can be classified into three types based on capabilities: General Artificial Intelligence (GAI), Super AI, and Weak/Narrow AI. GAI is proficient in performing any intellectual task as effectively as a human, while narrow AI is more prevalent and easily accessible. Super AI, boasting superior cognitive abilities, surpasses human performance in various tasks.

AI architectures comprise Multilayer Perceptron (MLP), Convolutional Neural Networks (CNN), Recurrent Neural Networks (RNN), and Generative Adversarial Networks (GAN). MLP, the foundational neural network design, consists of input, hidden, and output layers. CNN addresses computer vision challenges like image identification and classification. RNN excels in handling sequential data such as time series and natural language processing, while GAN produces data mirroring training data properties, utilizing a discriminator to verify input image authenticity.

This study aims to analyze the applications of AI and Machine Learning (ML) in biotechnology, healthcare, and genomics. It seeks to explore emerging technologies with substantial potential for human advancement, investigate regulatory and ethical considerations, and examine potential global use-cases and software integration in these fields. Additionally, the study probes into the increasing utilization of AI and ML across diverse sectors, including agriculture, medical biology, industrial biotechnology, healthcare, genomics, and bioinformatics.

In agriculture, AI and ML play a pivotal role in cultivating new plant traits through conventional methods such as plant rearing, micropropagation, and tissue culture. In medical biology, these technologies contribute to drug and antibiotic development, focusing on DNA and genetic manipulation. Industrial biotechnology leverages IoT technologies for enhanced data management and reduced specimen handling. In healthcare, AI is integral to precision medicine, while genomics benefits from AI insights into gene functions and disease risks. Bioinformatics applications encompass protein-protein interaction, biological sequencing, and functional structure analysis, aiding in drug discovery and complex systems. Key applications in bioinformatics include gene editing experiments, protein structure identification [Jumper et al., 2021], drug repurposing, and analysis of protein-protein interactions.

Methodology

This research investigates the global applications of AI and ML in healthcare, genomics, and biotechnology, focusing on feasibility and limitations. Utilizing a mixed-methods approach, both quantitative and qualitative methods were employed. An online survey covered AI & ML usage in daily life, biotechnology, genomics, and healthcare. Additionally, semi-structured interviews with 10 participants from diverse fields provided qualitative insights. RStudio software was used for data analysis, incorporating insights from interviews.

Experts from various domains were initially queried about the prevalence of AI in the current scenario. Subsequently, they shared insights on how AI is revolutionizing their respective domains. Several key themes emerged regarding challenges, potential solutions, and the future perspectives of AI and ML use.

AI's impact extends beyond healthcare and biotechnology, offering value in education and social institutions by creating skilled jobs and enhancing social life. However, challenges such as the erosion of manual labor, the digital divide, and potential effects on attention spans and IQs exist. Furthermore, inadequate digital literacy in rural areas may lead to an inferiority complex and a lack of basic knowledge, potentially resulting in increased disputes, decreased morals, and societal collapse.

From a psychological standpoint, AI can provide new insights into human behavior through monitoring social media, credit card spending, GPS data, and smartphone metrics. Challenges include potential compromises in human relationships, emotional impacts, and risks to physical and mental health. Privacy invasion and increased crime rates are additional concerns, and virtual interactions may contribute to feelings of loneliness, anxiety, and depression.

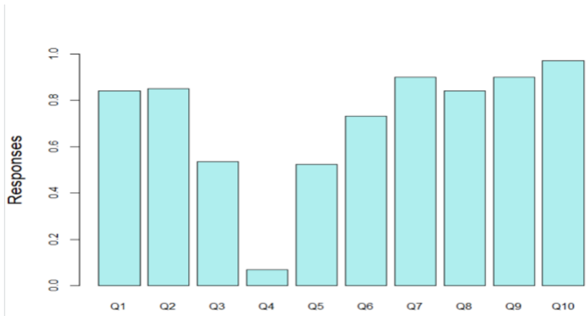
Ethical considerations were prioritized, ensuring confidentiality and anonymity through verification of the interviewees' official IDs. It is crucial to acknowledge limitations, such as sample size and potential survey response bias, when interpreting results for data validity.

Results

This section presents the analysis of the conducted survey using RStudio. The results of the survey, based on a sample size of 101 individuals, primarily composed of students, are interpreted.

Section-1: General uses of AI/ML in daily life

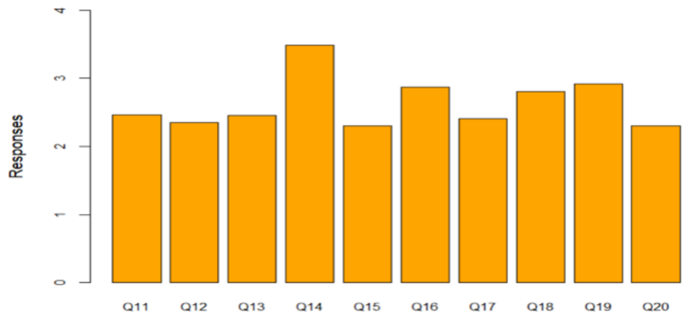
This section explores the widespread applications of AI/ML in everyday life, emphasizing the familiarity of the sample population with these technologies. According to the graph, a majority of individuals are aware of AI/ML in their daily activities, with navigation apps emerging as the most commonly used application. Conversely, the sample population exhibits lower awareness levels regarding AI/ML-based recommendation systems, as well as dating apps designed for suggesting potential matches.



Use of general AI/ML by sample population in daily life

Section-2: Use of AI/ML in the fields of Biotechnology, Genomics and Healthcare.

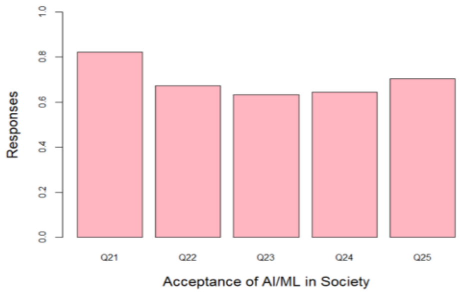
The present section explores the application of AI/ML in biotechnology, genomics, and healthcare, posing 10 questions on related applications and ethical considerations. A significant portion of the surveyed population supports the need for regulations to ensure responsible AI/ML utilization. However, there is dissent regarding the creation of synthetic models and data mimicking natural phenomena using AI/ML. Similarly, there is disagreement concerning the development of genetically modified organisms capable of thriving in harsh conditions for exploration purposes. Overall, the majority of the population does not share consensus on these particular concerns.



Acceptance of AI/ML in the fields of Biotechnology, Genomics and Healthcare

Section-3: Ethical and Psychological implications of AI/ML on society

The section posed five questions with Acceptable/Unacceptable options, addressing scenarios arising from AI/ML prevalence. If they align with the sample population's ethics and morals, the option was "Acceptable." Inferences drawn include generally acceptance of AI/ML in society, acceptance of challenges to human uniqueness in creative fields, and concern for job displacement due to AI/ML advancements.



Applications and Global Use Cases

1. Medical imaging

AI has significantly advanced medical imaging and diagnostics, revolutionizing the way medical professionals diagnose and treat various conditions. Applications of AI integration include image analysis and interpretation, tumor detection, disease classification, personalized treatment planning, real-time monitoring, data management and analysis, and radiomics. Microsoft Corporation, a multinational entity, has collaborated with the Department of Oncology at Addenbrooke's Hospital for over a decade to pioneer technologies for radiotherapy. Their project, OSAIRIS, utilizes open-source software to streamline the process from radiotherapy referral to treatment, reducing the time involved. Meanwhile, Thorina, founded by Eva van Rikxoort, focuses on using AI for personalized treatments in lung diseases. Both companies prioritize integrating AI into their services, emphasizing advanced lung image analysis and providing high-precision AI-based services for pharmaceutical companies. Through AI implementation in medical imaging, entities like Microsoft and Thorina enhance diagnostic accuracy, identify tumors, and elevate patient care.

Microsoft's Project InnerEye Open-Source Software (OSS) serves as a tool for medical imaging and quick contouring for radiotherapy, easing the workload of CT scans for cancer patients [Microsoft, 2023]. This software employs Convolutional Neural Networks (CNN) for automatic segmentation of medical images, developed through Microsoft Azure Machine Learning (ML) on 20 NVIDIA Tesla V100 GPUs. The model significantly accelerates end-to-end image segmentation and annotation in radiotherapy, achieving almost 13 times faster results with high accuracy. The software is freely available under an MIT open-source license, ensuring accessibility for the global medical imaging community.

Thirona's CAD4COVID utilizes AI with deep learning capabilities to predict COVID-19 and pneumonia through chest CT quantification. These technologies aid in identifying lobular regions affected by COVID-19 or pneumonia, minimizing the reliance on manual CT scans..

2. Robotic Surgery

AI and machine learning have significantly enhanced robotic surgery by improving precision, safety, and effectiveness. Key applications encompass patient-specific modeling, virtual simulation, assisted and autonomous surgery, image analysis, recognition, and learning from surgical data. AI enables the creation of patient-specific 3D models, real-time assistance for surgeons, and the autonomy of robots in performing specific steps under the surgeon's supervision. Image recognition aids in identifying target structures and vessels, while learning from surgical data facilitates outcome prediction and the refinement of surgical techniques. Safety enhancements include error detection and risk mitigation.

The Mayo Clinic, established in the late 19th century, has integrated over 15,000 Apple mobile devices into patient care and developed Synthesis Mobile, a platform integrating various healthcare systems. Additionally, the clinic has formed strategic partnerships with Google and NTT Venture Capital for a biomedical software startup called Inference. Presently, the Mayo Clinic is offering two da Vinci SP robot-assisted surgical systems to patients.

The da Vinci Surgical System, consisting of advanced instruments for minimally invasive surgeries, translates the surgeon's hand movements in real time via a console [Intuitive, 2023]. It provides high-definition 3D views of the surgical area and comprises a surgeon console, patient's cart, and vision cart. Evolving from da Vinci OS1 in 2000 to da Vinci OS4, which powers fourth-generation systems, the system aids in intraoperative decisions, offers insights, supports SimNow simulation technology, and integrates data communication among components.

3. Oncology research

AI and machine learning (ML) algorithms play a pivotal role in cancer research, offering capabilities such as early cancer detection, personalized treatment planning, accelerated drug discovery, prognosis prediction, and facilitation of precision medicine. Established in 1998, Google has made substantial investments in AI research and development, showcasing products like Google Assistant and seamlessly integrating AI across its services. The company is a key player in the competitive cloud computing industry, challenging giants like Amazon Web Services and Microsoft Azure.

Pioneering the field of cognitive computing, IBM and Pfizer stand out with Watson, the first commercially available cognitive computing capability. Pfizer has effectively employed Watson for Drug Discovery, customizing this cloud-based cognitive tool to enhance the identification of new drug targets and the formulation of patient selection strategies in immuno-oncology [Pfizer, 2016].

Deep Mind, a division of Alphabet, Inc. (Google's parent company), specializes in developing general-purpose artificial intelligence (AGI) technology. It utilizes raw pixel data as input, learning from experience, and integrating both physical and biological knowledge about protein structure.

Google's Deep Learning System (DLS) employs multiple Convolutional Neural Network (CNN) modules for the survival prediction of various cancer types. The system optimizes layer sizes and the number of layers using random grid-search techniques.

IBM's Watson AI, created by DeepQA, collaborates with Pfizer in immune-oncology research and drug delivery. The cloud-based software, IBM Watson Health for Drug Delivery, aids in the discovery of new drug targets and alternative indications. Leveraging cognitive computing, it dissects questions into keywords to identify statistically related phrases within the database, providing sensible and relevant results.

4. Next generation sequencing

AI and machine learning (ML) play a crucial role in next-generation sequencing (NGS) applications, spanning read alignment, variant calling, quality control, transcriptomics analysis, and clinical interpretation. Key players in this domain, such as Illumina and Nvidia, concentrate on advancing DNA sequencing and array-based technologies for genotyping and gene expression, contributing significantly to genomics and personalized medicine.

Illumina's TruSight Software Suite, developed by the company [Illumina, 2023], integrates AI and ML tools for variant analysis and interpretation in rare disease research. Components like SpliceAI, PrimeAI, and Emedgene utilize deep Residual Neural Network architecture (ResNET) and deep learning neural networks. On the other hand, Nvidia's Clara Parabricks, designed for secondary genomic analysis, delivers rapid, cost-effective results for both DNA and RNA sequences.

Within Illumina's TruSight Software Suite, SpliceAI, PrimeAI, and Emedgene operate on deep learning neural networks, streamlining and automating the variant classification process. Similarly, Nvidia's Clara Parabricks serves as a comprehensive software suite for secondary genomic analysis, ensuring swift and economical outcomes for extensive and intricate sequencing datasets [Nvidia, 2023]. Both companies remain committed to advancing next-generation sequencing and ML technologies, aiming to enhance accuracy, efficiency, and overall quality in genomic research.

5. Genetic Engineering

AI and ML play a crucial role in genetic engineering, encompassing various applications such as gene editing, gene expression, synthetic biology, metabolic engineering, and protein engineering {Garg, 2022]. Companies like Zymergen leverage the integration of genetic engineering and ML to develop programmed microorganisms. Zymergen utilizes an in-house Python-based system named Helix to translate human-interpretable ideas for gene modification into a low-level DNA language. This modified genetic information is then introduced into microorganisms through the insertion of a physical DNA loop between two points in the DNA sequence [Zymergen, 2023].

To assess the performance of these modified microorganisms, small-scale, high-throughput experiments are conducted. Python is employed for data preprocessing, retrieval, model updating, and recommendation generation. Experimental outcomes and biological features are used to train ML models, which, in turn, provide recommendations for designing strains. Automated robots support parallelized small-scale experiments, enhancing efficiency.

Biological feature extraction focuses on metabolism, recognized as the quickest pathway for enhancing desired chemical production. Metabolic networks are employed to derive traditional graph metrics for ML application. Additionally, Flux Balance Analysis (FBA) is utilized to interpret graphs in scientific content. This integrated approach optimizes the genetic engineering process, combining AI and ML for efficient and effective results.

6. Clinical Data Managment

AI and ML are essential in clinical data management, offering a holistic perspective on patient health, data cleansing, predictive analytics, clinical decision support, and patient monitoring.

Established in 1999, Medidata Solutions, Inc. is a technology firm specializing in cloud-based solutions for clinical research in the life sciences sector. Their software platform, Rave, integrates clinical data management, pharmacovigilance, and clinical research, facilitating seamless information flow and addressing data quantity and integrity issues. Rave encompasses various types tailored to meet diverse pharmaceutical field requirements, such as Safety Gateway, EDC, Imaging, Targeted SDV, Coder, Safety Analytics, and RTSM. These tools contribute to pharmacovigilance, safety management, medical image management, risk-based monitoring, medical coding, safety analytics, and supply management. Medidata's continuous innovation has revolutionized clinical trials by boosting efficiency, data quality, and collaboration among researchers, sponsors, and regulatory agencies.

Feasibility

Artificial Intelligence (AI) and Machine Learning (ML) offer significant potential in healthcare and biotechnology, leveraging data-driven insights from diverse sources for precise predictions and informed decision-making. These technologies accelerate drug discovery by predicting candidates, simulating molecular interactions, and optimizing drug properties. Analyzing individual genetic and molecular data enables personalized medicine.

AI and ML play a pivotal role in early disease detection, accurate diagnosis, and prognosis through the analysis of medical images, genomic data, and clinical records. They identify biomarkers indicating disease presence or progression. In genomics, these technologies excel at analyzing gene interactions, predicting functions, and discovering mutations linked to diseases.

Protein structure prediction is a domain where AI and ML excel, forecasting 3D structures to advance drug design and disease research. In agriculture, they optimize crop yield, detect diseases, and improve breeding for sustainable and efficient food production.

In synthetic biology and bioengineering, AI and ML design and simulate biological systems [Garg, 2022; 2024] for diverse applications like biofuel production and pharmaceutical synthesis. Ensuring regulatory compliance and quality control involves analyzing data to predict potential issues.

While AI and ML hold immense promise, their success relies on reliable data. Implementation demands interdisciplinary collaboration among biologists, data scientists, and computer scientists. Ethical and regulatory challenges arise from handling sensitive biological data, necessitating the development of ethical guidelines. Rigorous validation is crucial before applying findings in practical applications. A study evaluated the feasibility of an AI-powered web-based clinical decision support system for treating depression in adults, employing a digital AI-powered CDSS.

Limitations

AI and ML technologies present various limitations, such as training complexities, heightened unemployment risks, challenges in managing substantial changes, dependency on explicit instructions, increased cybercrime threats, absence of human and social values integration, and a decision loop.

It is imperative to provide comprehensive training for medical professionals, ensuring accurate data for optimal AI and ML performance. Notably, the healthcare sector faces a potential rise in unemployment due to these technologies, necessitating a delicate balance across different sectors.

Striking this balance is crucial, given that pivotal decisions can significantly impact life and death situations.

While AI operates strictly on given instructions, humans possess a unique ability to observe behavioral changes and synchronize with patients, reducing complications. The escalating sophistication of cybercrimes underscores the need to safeguard patient credentials through AI to mitigate risks effectively.

The incorporation of human and social values into AI remains challenging. Despite AI's ability to offer appropriate treatment based on ML or diagnosis, it often overlooks inherent social values influencing decisions. Physicians, performing a broader range of tasks than AI algorithms, can adapt to various situations even with limited access to data.

Conclusion

The potential benefits of AI and ML technologies must be meticulously managed and adapted to ensure effectiveness and safety. This project explored their applications in biotechnology, healthcare, and genomics, emphasizing the importance of ethical, legal, and moral considerations. Raising awareness of AI and ML models across all societal segments, including rural populations, is essential. Establishing organizations and forums for regulating the ethical use of AI, with a primary focus on user privacy and data protection, is recommended. Future research should prioritize ethical and feasible levels of investigation into the applications of AI and ML in healthcare and biotechnology, drawing insights from experts and the general population while analyzing potential challenges for the future.

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