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AN OVERVIEW OF NEUROSCIENCE AND ARTIFICIAL INTELLIGENCE: APPLICATIONS, EMERGING TRENDS, CHALLENGES & FUTURE DIRECTIONS

Tvisha Pundir*

Middleton High School, Middleton WI, USA.

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***Corresponding Author**

Tvisha Pundir

Middleton High School,

Middleton WI, USA.

ABSTRACT

During the recent past, Artificial Intelligence has been gaining immense importance due to its vast application in replicating human actions and behaviour. This study highlights the significance of AI to the fields of healthcare, neurotech, cognitive therapies and brain-computer technologies. It discusses the commonalities between the neurons in the human brain and the artificial neural networks. The entire study focuses on the applications of neuroscience and artificial intelligence in diagnosis, treatments and therapies for neurological/behavioural disorders such as Traumatic Brain Injury(TBI), Alzeihmer's Disease and Parkinson's Disease. However, this comes with associated challenges and limitations as the human brain is capable of performing complex tasks with ease. The study discusses how the human brain is far more dynamic and interactive and can function by deriving inputs across multiple sources and environments. This study covers appropriate suggestions such as hybrid intelligence between human cognition and AI systems, role of interdisciplinary research and bridging the gap between artificial intelligence and biological intelligence to curb the challenges as well as provide future directions. The entire study has been conducted in context of the growing importance of AI tools and the projected growth in the neuroscience market over the coming years.

KEYWORDS: Neuroscience, Artificial Intelligence, Brain, AI applications in Neuroscience, AI applications in healthcare, Brain-Computer Technologies.

INTRODUCTION

According to S&S Insider as published in Globe Newswire (Austin Nov.11, 2024), the Neuroscience market size was valued at USD 35.3 billion in 2023 and is projected to reach to USD 50.2 billion by 2032, growing at a compound annual growth rate (CAGR) of 4.0% over the forecast period of 2024-2032.[1]

The field of neuroscience holds significance in understanding how the brain and nervous system work, leading to enhanced treatments for brain disorders and related areas. The study of the brain involves the structural biology of the human nervous system as an integral part of the human body. This helps us in understanding the process of behaviour, thoughts and emotions which are controlled by the brain.

According to the definition proposed by King's Neuroscience, it is the study of the nervous system – from structure to function, development to degeneration, in health and in disease. It covers the whole nervous system, with a primary focus on the brain. Incredibly complex, our brains define who we are and what we do.[2]

The knowledge serves as a foundation in treating brain conditions like Parkinson's, Alzheimer's as well as brain injuries occurring due to accidents and trauma. It also helps us to understand the role of the human brain in cognitive and memory function.

ELEMENTS OF NEUROSCIENCE

According to the National Institute of Child Health and Human Development, the different branches of neuroscience have been identified as follows:[3]

- **Developmental neuroscience:** It describes the processes leading to brain formation, growth, and modification.
- **Cognitive neuroscience:** This branch is related to the ways in which the brain creates and controls thought, language, problem-solving, and memory.
- **Molecular and cellular neuroscience:** It explores the genes, proteins, and other molecules which are responsible for the function of the neurons.
- **Neurogenetics:** It is the field which focuses on inherited changes to neurons, including the study of genetic diseases.
- **Behavioral neuroscience:** This field examines the brain areas and processes underlying the action mechanism in humans.
- **Clinical neuroscience:** This field deals with the treatment and prevention of neurological disorders and rehabilitation of nerve injury patients.

- **Neurophysiology:** It is the study of the nervous system and its functions.
- **Sensory neuroscience:** This branch examines features of the body's sensory systems and how they process sensory information.

BACKGROUND- NEUROSCIENCE & AI

According to Cole Stryker (IBM), artificial intelligence (AI) is a technology that enables computers and machines to simulate human learning, comprehension, problem solving, decision making, creativity and autonomy.[4]

As can be observed over the evolution of AI, neuroscience has played an important role in inspiring advanced models in AI. Likewise, AI has supported the framework to simulate models in neuroscience, thus leading to growth in both these areas.[5]

According to Neha Mathur(2023), parallels drawn between the two fields of neuroscience and AI have resulted in neuroscience inspired early AI models. The neurons in the human brain have been compared to artificial neural networks (ANNs) and both these have several interconnected units that work in synchronisation with each other. Likewise, the concept of Hebbian learning and brain structure helped Frank Rosenblatt design a simple ANN called perceptron in the 1950s.[6]

According to Zador(2024), artificial intelligence intends to imitate intelligent human behaviour. For this purpose, the simplest way is to engineer the brain in reverse mode. At the same time, neural networks hold the key to being the nearest version of extensive computations of the brain. These are similar to the models having the capacity to solve the most complex situations.[5]

The essence lies in the synergy between neuroscience and AI for advancing technology and understanding the brain like never before.

The intersection between neuroscience and AI can have a massive impact on the advancements in healthcare, neurotech and cognitive therapies. This can lead to major breakthroughs in treating neurological disorders and diseases. The complexities of human brain functions and data can be harnessed using artificial intelligence which can in turn lead to effective diagnosis and customised treatments. This can also lead to development of brain-computer technologies based on a better understanding of human brain cognition.[7]

APPLICATIONS OF NEUROSCIENCE & AI

- **Brain imaging technologies: PET and MRI**

Researchers conducting studies on the brain frequently use brain imaging tests like PET-Positron Emission Tomography and MRI- Magnetic Resonance Imaging. The effects of brain diseases, injuries occurring as a result of Traumatic Brain Injury as well as the effect of drugs/chemicals can be studied using PET and MRI. The researchers can develop benchmarks by studying the intricacies of the brain under normal circumstances. The brain images from an affected person can be compared to these established benchmarks. In PET technology, the patient is administered a dose of radioactive compound tracer which helps in measuring the different amounts of activity occurring in different parts of the brain depending on the colour variations. However, in MRI technology, the brain activity is measured by the amount of blood flow to that particular area within the brain. So, both these activities are very helpful to researchers in learning how a normally functioning brain works by showing which brain areas are active during certain tasks, and what kinds of variations exist among individuals.[8]

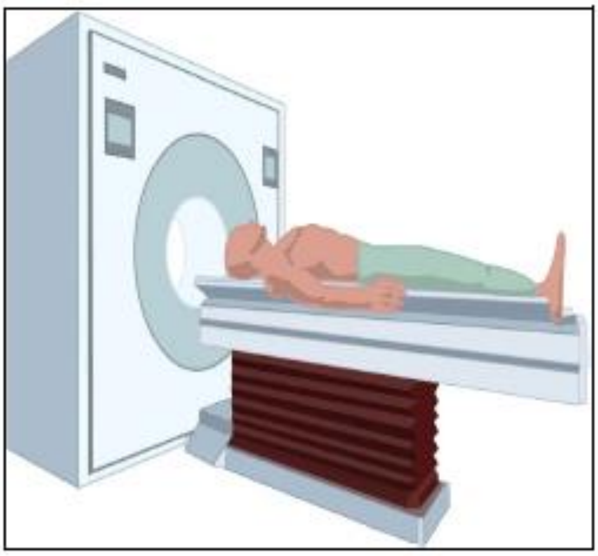

Figure 1: Positron Emission Tomography.

Source: Genetic Science Learning Centre (2025)

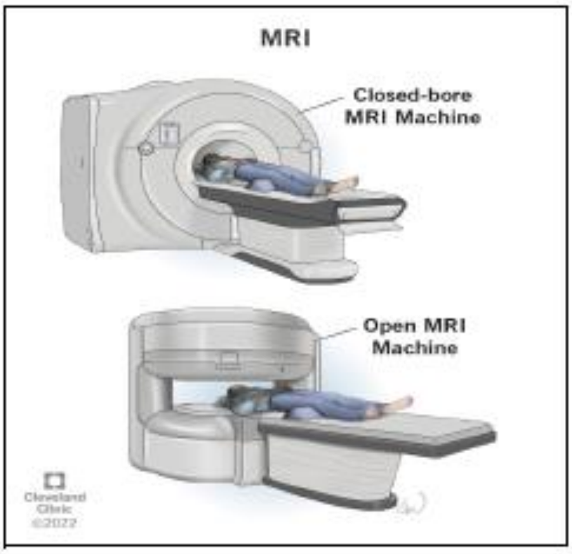

Figure 2: Magnetic Resonance Imaging.

Source: Cleveland Clinic (2022)

- **Knowledge of neural circuits and cognitive processes for treating neurological/behavioural disabilities**

According to Nakajima & Schmitt(2020), in order to gain more knowledge about the neural circuits present in the brain and the computations responsible for specific cognitive processes, we need to be able to assess the neural movements corresponding to these particular cognitive processes. New developments in this area of technology have led to processes which can enable and disable activities in these neural circuits while recording them across tonnes of neurons present in different parts of the human brain which are functional during specific cognitive behaviours.[9]

Further technological advancements can allow us a better understanding of these neural networks and their vital use of sensory stimuli leading to complex behavior. This understanding can find useful applications in the field of artificial intelligence, thus providing solutions and treatments for many neurological/behavioural disabilities.

Emerging Trends and Technologies

- **Neuromorphic computing: Hardware designed to mimic the brain**

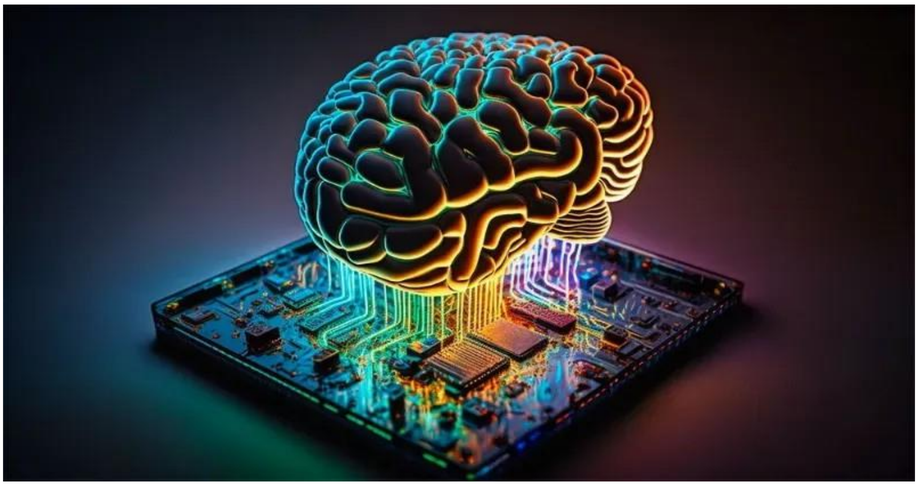

Figure 3: Neuromorphic Computing.

Source: thedigitalspeaker.com (2025)

According to Hess(2025), neuromorphic computing is an approach to mimic the brain in terms of hardware design and algorithms. Researchers working in this field are designing a multi- layer system of computing to match the performance of the human brain. The human brain outperforms conventional computers as it needs no power and can compute even if the input data is not well-defined. IBM researchers are using the human brain as a benchmark for the newer versions of software and hardware which can be used effectively to deal with huge datasets required by computing tasks in artificial intelligence.[10]

As we all know, the human brain functions by means of neurons and synapses for memory formation and learning. However, in a typical computer processor the memory region and computing region are placed separately. This leads to time and energy being lost in the process of data being carried back and forth for processing. But in a neuromorphic architecture that includes on-chip memory, memory is closely intertwined with processing on a fine level — just like in the brain. This is a chief feature in IBM's in-memory computing chip designs.[11]

The benefit of having this type of structure becomes very useful when handling heavy datasets as in Artificial Intelligence applications including AI training and inferencing.

- **Real-time brain simulations and digital twins of neural systems**

Figure 4: The Digital Twin Brain: A Bridge between Biological & Artificial Intelligence.
Source: spj.science.org (2025)

According to Xiong et. al.(2023), path-breaking developments in the fields of neuroscience and AI have inspired the researchers to further understand the capacities of the brain and simulate it using computational models. In particular, neurological research advancements have highlighted the use of knowledge about the human brain and function to launch artificial neural networks successfully and making the network architecture even more important. By combining all these elements, we can have a clearer understanding of the emergence of intelligence from the multi-level brain repositories.[12]

The Digital Twin Brain (DTB) bridges the gap between biological and artificial intelligence. It provides a platform to comprehend the human brain's basic and complex neural processes involved in different functions and disabilities. Finally, this leads to a combination between the comprehension, simulation and control of the brain functions under specific conditions. The aim is to project the results of external treatments whether physical or chemical, thus devising new therapies for brain disorders like Parkinson's Disease. Also, these models provide deep insights into the underlying causes for neurological disorders as well as in designing effective treatments. The advantage of DTB is to provide cost effective assessments for diagnosis and treatments.

The DTB is made up of 3 components:

1. The brain structure which provides the basic knowledge,
2. The bottom-layer models for generating brain functions,
3. A wide spectrum of applications. The brain atlases organise the brain's network within the DTB.

The DTB was initially proposed to be used by NASA, United States. Ever since it is being used by the manufacturing and healthcare fields by using actual datasets for testing. Virtual experiments can be conducted by using DTB to understand cognition and behavior processes. However, more efforts are needed to reach the stage of creating a replica of the brain.[13]

- **AI in the study of Brain Aging for personalized medicine and neurological disorder treatments**

According to Surianarayanan et al (2023), the neural networks within the human brain have inspired the development of complex neural architectures leading to applications for speech recognition and text processing and many more functions. Also, reinforcement learning (RL) in humans has supported the replication of these processes in artificial systems, thus facilitating the use of complex commands by these systems. Artificial Intelligence has the capability to assess complex data and produce patterns. So, it can be used to process the complex datasets provided by the human brain. Specifically, Convolutional Neural Networks (CNNs) can derive patterns like the human brain's organised methods by analysing the multiple stage visual inputs. CNNs architecture supports them to derive different visuals by making use of sorting and collating available data. CNNs help in estimating the age of a human brain from the structural MRI scan inputs.[14] The human brain cavities filled with cerebrospinal liquid help in predicting the brain age. This helps in detecting the presence of neurological diseases such as Alzheimer's Disease and Dementia.

CHALLENGES & OPPORTUNITIES

These developments as can be explicitly seen have led to path breaking advancements. However, they have not done so without certain challenges and limitations. The challenges can be broadly classified into two categories:

- **Scientific challenges:** These may arise as a result of understanding the brain's complexity.
- **Technological challenges:** These may arise due to the limitations of computing power and data limitations.

Though the AI models formed based on the knowledge gained from the field of neuroscience are based on hierarchical architecture as in the case of the human brain, still there remain certain differences or limitations. The AI models function through simulations and algorithms whereas in the human brain, it functions through actual neurons exchanging electrochemical signals.

According to Payong(2024), although algorithms are inspired by brain functions, a number of limitations still remain as follows:[15]

- **Complexity:** The human brain is designed to access information from different sources, process it in real time and act in accordance with the scope for flexibility. This clearly indicates that the brain mechanism is much more dynamic than the latest algorithms.
- **Transfer Learning:** The best algorithms need a lot of training and retraining in transferring acquired learning to perform complex tasks. However, the human brain has been designed to perform such tasks at ease.
- **Multimodal Learning:** The human brain has the capacity to derive from different senses and environments to process the information all together. However, even the latest AI models can only work in a single mode so far.

The human brain is far more dynamic and interactive because of its senses, information processing and environment response mechanism. So, it is way too far for the AI models and current algorithms to match up the finesse of the human brain. The AI models can offer advantages in functions where sight, sound and sensation can merge in a seamless manner. Also, their outcomes can be enhanced by using new approaches such as neuro-modulation, which can replicate the human brain learning mechanism. Additionally, memory-augmented networks attempt to emulate some unique qualities of human memory.[15]

However, mounting evidence has demonstrated that artificial intelligence is vulnerable when facing adversarial situations that biological intelligence can easily avoid.[16] Biological intelligence has the capability to perform increasingly tough tasks including cross-functional tasks, whereas artificial intelligence can only perform tasks which are based on already configured parameters. The knowledge about the mathematical models behind biological intelligence is lesser known and cannot be totally used for devising artificial intelligence. So, it is very critical to understand the way in which the human brain processes inputs. An interconnected model between the human brain and AI models can synchronise the functionality of both and derive a common and more efficient platform. This means that accumulated and upcoming knowledge about biological intelligence can be transferred to artificial intelligence in the form of networks.[13]

According to Surianarayanan(2023), another challenge is to have a holistic view by creating datasets which follow an interdisciplinary approach using neuroscience, artificial intelligence and other biological systems. These datasets can only be created by engaging more and more people across different disciplines. The AI team should not just focus on providing solutions in the form of algorithms, but by being driven to the deeper level of understanding the mechanism.[14]

Another challenge is to assess the AI models in real-life settings with latest data rather than depending on historical data. In order to fill the gap between AI models' performance and clinical efficiency, current medical data should be accessible and shareable. Actual progress can be achieved by collaboration between teams across different functions with availability of data. However, in the USA, the privacy and security of the healthcare data of an individual are protected by the Health Insurance Portability and Accountability Act (HIPAA) rules.[17] So, the current healthcare environment does not support data sharing. But it is mandatory for building efficient systems with a complete understanding of a wide range of aspects concerned.[18]

SUGGESTIONS & FUTURE DIRECTIONS

The key to harnessing the power of artificial intelligence in the field of neuroscience lies in the following:

- Hybrid intelligence: Collaboration between human cognition and AI systems.
- AI models achieving general intelligence inspired by the brain.
- Bridging the gap between artificial and biological intelligence.
- The role of interdisciplinary research.
- Collating large datasets from teams across different functions.
- Using real- time data for effectiveness in clinical practices.
- Laying out standards and exceptions (besides laws such as HIPAA) for data sharing.
- Training AI models with current data of patients instead of historical data.
- Maintaining diverse and inclusive data repositories for effective training and retraining of AI models for repetitive exposure to improve efficiency and accuracy.
- According to Stryker(2024), Generative AI or "gen AI" is the way forward. It involves models which can create different forms of complex content consisting of text, images, audio and video depending on the request that is fed. The baseline for generative AI

models remains the same basic data which is used for training and retraining. This further supports the process of generating similar(not same) output, which may be more realistic and closer to the expectations.[4]

CONCLUSION

The intersection of AI and Neuroscience is a very critical field, combining both areas. It is helping achieve major milestones in the diagnosis and treatments of neurological disorders. Despite challenges, such as the human brain's finesse and the limited capabilities of current AI models, latest developments on neuromorphic computing and brain simulations, and future AI-based healthcare solutions may offer respite to handle these challenges in a constructive manner. The future of this interdisciplinary area of research depends on uniting biological and artificial intelligence. By means of a continuous innovative approach in the development of AI models and data exchange across functions and teams, it can help us expand our understanding of the human brain and apply to real-life situations such as neurotech.

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