

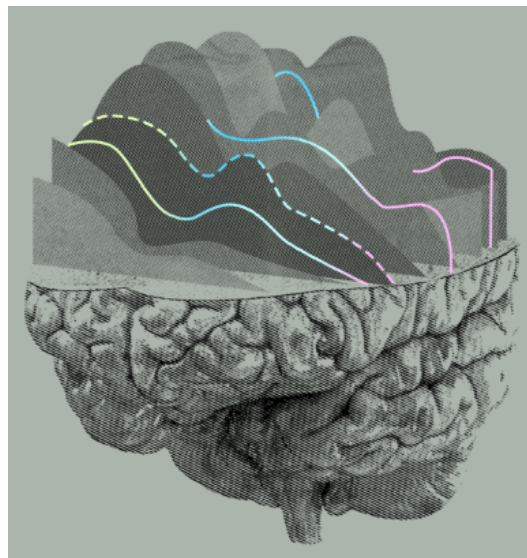
Paper: *An Integrated Brain-Machine Interface Platform With Thousands of Channels*

Elon Musk; Neuralink

<https://www.jmir.org/2019/10/e16194/>

## Introduction

Emerging technologies may not always defer to scheduled upgrades or updates. Engaging in a technological race to rival the capacities of the human body entails inherent risks. The innate imperfections woven into our daily activities underscore the complexity of the human experience. Just as external factors can limit one's ability to assist others, individuals may also confront mental health struggles, accidents, or lingering health issues requiring medical attention. In these instances, timely acknowledgment and potential resolution of these challenges are achievable through suitable means and interventions.



*Figure 1: Engineering with brain*

Introducing Neuralink, the brain of the future. Have you ever experienced a moment upon waking when your mind is a whirlwind of thoughts, like a TED talk competing with headlines from the Irish Times, a Spotify coffee playlist, and the meticulous organisation of your Outlook calendar in your absence? Neuralink, initiated by the visionary Elon Musk, represents a revolutionary advancement in brain technology.

Within our brains reside billions of neurons, each playing a crucial role in sending and receiving information. To be more specific, dendrites receive signals, while a cell body known as the soma processes these signals, and the axon transmits them

outward. Neuralink, therefore, stands as a groundbreaking innovation in the realm of brain technology.

## Methods

. The "Neuralink" Brain-Machine Interface has a history nearly as ancient as our understanding of electricity itself. It's long been known that electric currents can trigger the activation of muscles and nerves. When small currents are applied to an electrode, it can set off one or more action potentials in neighbouring neurons, thanks to the influence of a shifting electric field.

This groundbreaking technology allows for the generation of specific patterns of neural activity, capable of evoking desired sensory experiences, such as the sensation of holding an object or even conjuring a visual image. Moreover, it has the potential to mitigate or entirely halt the abnormal activity patterns associated with neurological conditions like Parkinson's disease, which leads to movement impairments.

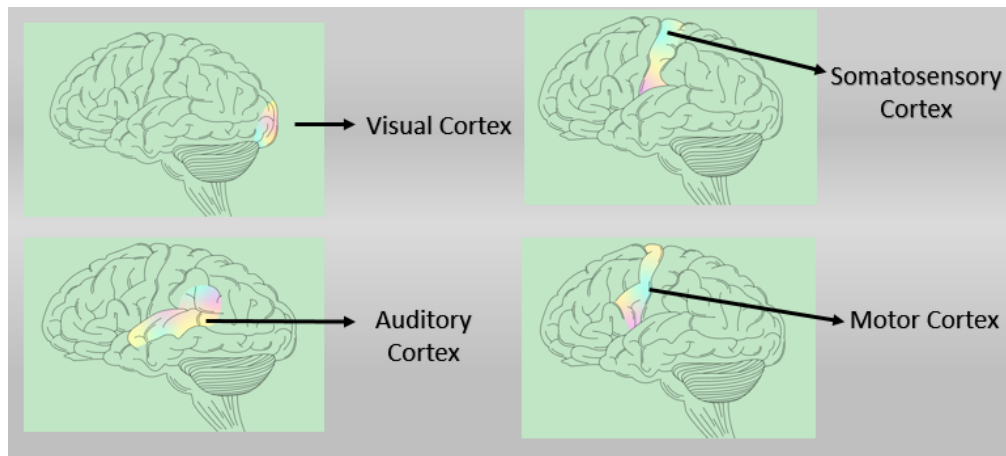
Various techniques have been employed to enhance this technology, but in every innovation lies a unique quality that sets the product apart.

- Ultra-Fine polymer probes.
- A Neurosurgical Robot.
- Custom High-Density Electronics.

One of the primary challenges in neural engineering, and a significant surgical hurdle, involves the precise placement of electrodes within the human body. When considering how Neuralink competes within the field of neural engineering, it becomes apparent that it directly interfaces with crucial parts of the brain.

Neuralink competes effectively with specific regions of the brain. For instance, it accurately interfaces with the Visual Cortex (as shown in figure 2), responsible for human vision. Additionally, it interfaces with the Auditory Cortex (also in figure 2), responsible for processing auditory sensations such as listening and hearing. Furthermore, Neuralink engages with the Somatosensory Cortex (figure 2), responsible for the sense of touch and feeling. Lastly, it connects with the Motor Cortex (figure 2), which plays a pivotal role in planning and executing the brain's commands for day-to-day activities.

This technology represents a formidable contender in the realm of neural engineering, and it has consistently pushed the boundaries of what's possible in this field.

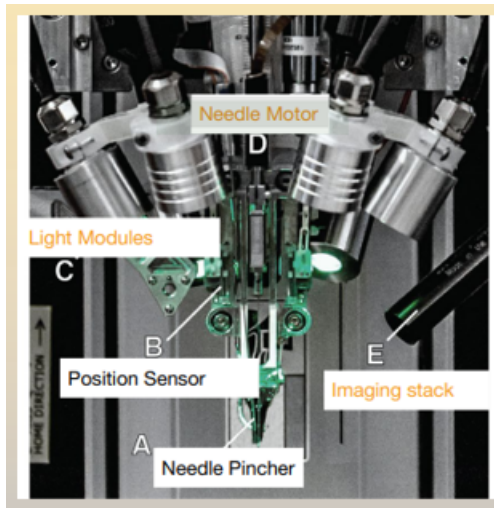


*Figure2: Neuralink competing with these parts of the brain*

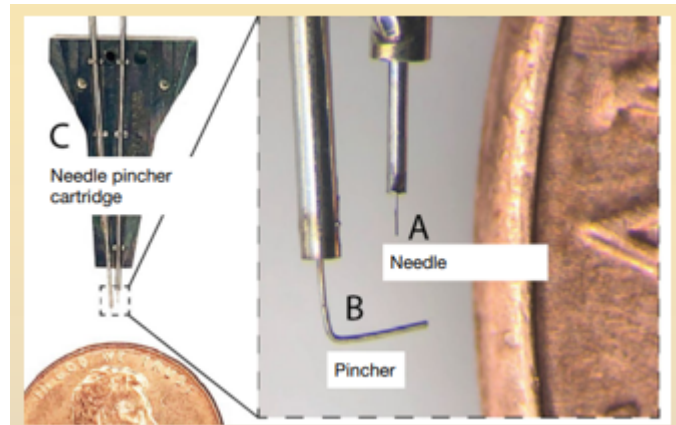
The Neuralink concept involves the use of ultra-fine probes, with the aim of implanting 96 polymers, each of which contains 32 electrodes. This results in a total of 3072 electrodes. In addition, spike-detection software is being developed to thoroughly analyse the functionality of the embedded chip, enabling early detection of any issues.

These threads, organised into arrays of 48 or 96 threads, each containing 32 independent electrodes, are crucial components of this technology. The method employed to achieve this is known as "Flip-chip bonding," which enables the creation of a compact electronic package and a novel alignment process essential for accommodating 3072 channels.

The use of a Neurosurgical Robot is a highly efficient approach, significantly reducing the risk associated with traditional surgical procedures. This robot is responsible for the precise insertion of the Neuralink and ensures avoidance of vasculature while recording data from various regions of the brain, resulting in accurate readings. The robot comprises a needle, pincher, and cartridge, as illustrated in Figure 5. The process involves Imaging stacking for enhanced precision and control.



*Figure 4: Neurosurgical robot*



*Figure 5: Detailed view needle*

To provide a detailed visualisation of the insertion process, it's essential to highlight the key components, including the light modules and position sensor, as depicted in Figure 4. The Neurosurgical Robot performs this intricate procedure with precision.

Using the integrated custom software suite, the robot is capable of preselecting all the insertion sites with great accuracy. It employs an auto-insertion mode, allowing for the rapid insertion of up to six threads, each containing 192 electrodes per minute. This efficient process ensures that the entire insertion can be completed within a maximum time frame of 60 minutes.

The ultimate goal of this technology, represented by Neuralink, is to achieve an unprecedented scale of data acquisition. With a remarkable capacity of over 1024 channels, it facilitates the extraction of a vast amount of information directly from the brain. This capability holds the promise of groundbreaking insights and applications in the field of neuroscience.

Custom high-density electronics heavily rely on contemporary techniques involving highly configurable Application Specific Integrated Circuits (ASICs). Particularly in the context of chronic reading, where thousands of electrode sites are involved, this presents substantial challenges in terms of electronics and packaging. The array assembly must be designed to be significantly smaller, often achieving a scale as compact as 20 times smaller compared to the dimensions of the human brain. This miniaturisation effort is essential for effective integration. Within this setup, there are approximately 256 individually programmable amplifiers.

Peripheral control circuitry plays a pivotal role in serialising and digitising the output data. To achieve this level of functionality, a number of ASICs are seamlessly integrated into a standard PCB (Printed Circuit Board) using flip-chip integration techniques. This approach ensures efficient and reliable performance of the high-density electronics, addressing the unique demands of chronic reading applications.

## Findings

In our contemporary world, neural engineering stands as a beacon of hope for individuals with disabilities, offering them a unique avenue to enhance their productivity and quality of life. While the journey of innovation may require time to fully mature, its transformative impact ultimately simplifies lives and empowers individuals to not just survive but thrive.

The sustainable evolution of these innovations holds the key to unlocking a multitude of future technologies. It not only provides a path towards lasting solutions but also instils hope and paves the way for a healthier way of life. This paper underscores the methods that streamline this process, marking a significant milestone for generations to come.

Numerous mechanisms have been explored for addressing neural-related issues, but the system described here represents a leap forward for future generations. It's important to note that these advancements are currently undergoing clinical trials involving animal subjects. Specifically, two systems, System A and B, have been implemented in male Long-Evans rats.

In the case of System A, impressive electrophysiological recordings indicate the capacity to record from 1344 out of 1536 channels. Meanwhile, System B exhibits even more remarkable capabilities, simultaneously recording from all 3072 channels. Furthermore, an application is in development for spike detection, enabling the real-time digitization of broadband signals and the identification of action potentials, commonly known as spikes, through an online detection algorithm. These advancements hold immense promise for the future of neural engineering and its potential to transform lives.

## Discussion

Every innovation in the field of neural engineering holds the potential for practical applications and novel approaches. These advancements have the capacity to significantly enhance spinal stimulation techniques and open up a wide array of therapeutic possibilities. Notably, they enable Brain-Machine Interfaces (BMIs) with high channel counts and single-spike resolution, marking a substantial leap forward.

Moreover, this research platform serves as a critical stepping stone for the development of human clinical implants, allowing for the rapid refinement of these devices. This iterative process facilitates the enhancement of signal processing and decoding algorithms, ultimately driving the progress towards fully implantable devices.

The capabilities within the realm of neural engineering consistently evolve, addressing and overcoming limitations by integrating the latest technologies. Thin-film probes, with their smaller size and ability to avoid vasculature interference, can be customised to suit specific task requirements. The use of Application Specific Integrated Circuits (ASICs) further contributes to flexibility and supports the implementation of a high channel count within practical size and resource constraints. These innovations promise to revolutionise the field of neural engineering, offering versatile solutions to complex neurological challenges.

## Interesting

Indeed, the foundation and companies founded by Elon Musk are fueled by his unique and visionary ideologies. His overarching goal has always been to improve the quality of human life. This vision has manifested in various groundbreaking innovations across different industries.

- In the realm of automobiles, his leadership at Tesla has transformed the automotive industry with electric vehicles, making a significant contribution to sustainable transportation.
- Through Starlink, he has ventured into the networking sector, aiming to provide global internet coverage through a satellite constellation, thereby expanding connectivity across the world.
- His recent foray into the world of information technology with projects like Twitter for IT showcases his determination to revolutionise communication and information sharing.
- Furthermore, his pursuit of advancements in the biomedical field with Neuralink signifies his commitment to enhancing human capabilities and addressing neurological challenges.
- Elon Musk's impact in each of these diverse fields is undeniable, and while it may seem audacious or even "crazy" at times, the practical implications of his

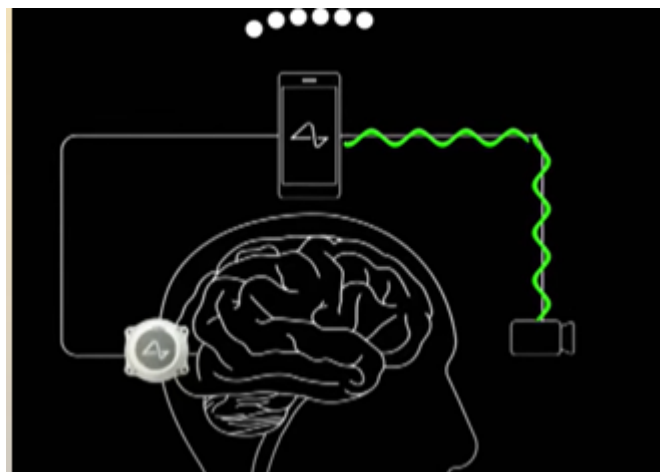
innovations are profound and have the potential to shape the future in remarkable ways.

## Significance

The progress being made in the field of biomedical innovation, exemplified by projects like Neuralink, represents a significant leap forward. Currently, these initiatives are in the midst of animal clinical trials and are awaiting FDA approvals to commence clinical trials involving humans. This approach offers a unique and promising way to address conditions such as Parkinson's disease, Huntington's disease, and disabilities like blindness and hearing impairment.

Neuralink, as an innovation, comes with its set of advantages and limitations, as is typical for any groundbreaking technology. These limitations serve as valuable feedback for refining and upgrading future iterations or improved versions of the product.

The introduction of "Neuralink N1" represents a remarkable milestone, showcasing the fundamental capabilities of the brain. Notably, it places a strong emphasis on overcoming blindness, a critical achievement illustrated in Figure 6. This innovation, rooted in neural engineering, competes effectively with various aspects of brain function, as detailed in the methods employed. It is poised to make a substantial impact on the lives of individuals facing neurological challenges and disabilities.



*figure 6: Neuralink N1 embed for blindness*

## Limitations

Smartphone to its chip. However, in the case of Neuralink, we're embedding chips within the human brain itself, a concept that brings both incredible possibilities and unique challenges.

One of the limitations that Neuralink faces, albeit to a lesser extent compared to smartphones, is the potential for chip hacking. Given its integration with the human brain, security is of paramount importance in the realm of medical devices. Neuralink has taken a proactive approach to address this concern, implementing security measures at every layer, including robust cryptography, defensive engineering practices, and extensive security audits.

However, there remain valid concerns, particularly regarding the storage of feelings and thoughts within the chip. Data transfer and connectivity to various devices introduce new challenges, requiring careful consideration and practical analysis. It's crucial for mobile application development to remain continually updated, as the application serves as the primary interface for tasks like spike detection, making it a critical component of the overall system.

## Directions for future work

The emergence and actualization of technologies like Neuralink have the potential to catalyse future innovations in remarkable ways. It's notable that prominent figures like Amazon CEO Jeff Bezos and Bill Gates have shown interest and support for brain implants, although these ideas are still in the proposal stage and undergoing clinical trials.

The concept you describe, where a chip implanted in the brain could capture and store data over the course of 20-30 years, is intriguing. Storing this brain data on data servers and potentially embedding it back into a human prototype could indeed have profound implications. It's a notion that touches on the intersection of technology and human existence, potentially offering the possibility of a form of rebirth or the replication of certain cognitive patterns and actions.

However, such concepts raise complex ethical, philosophical, and practical questions, and the feasibility and ethical considerations surrounding the long-term storage and transfer of human consciousness remain topics of intense debate and exploration within the scientific and ethical communities. The advancement of technologies like Neuralink certainly opens up new frontiers for discussions on the nature of consciousness, identity, and the boundaries of human existence.