Data Science is Central to Ongoing Advancements in Neuroscience

In 2018, *Nature Methods* published an article stating that "Neuroscience is experiencing a revolution" [1]. In a field commonly associated with benchtop assays and behavioral outcomes, the paper had little to do with imaging, microscopy, or chemical intervention. Instead, this article introduced a novel computational approach, implementing a neural network-based model to infer functional relationships between active brain cells. As developments in neuroscience continue to unfold, that article is one of many suggesting that computing, automation, statistical analysis, and machine learning will increasingly be at the core of major research achievements and clinical applications in neuroscience.

Since the design of the transformer architecture in 2017 [2] and commercialization of scaled machine learning in recent years, large language models (LLMs) have rapidly become a ubiquitous technology [3]. Though much public attention and industry effort has focused on LLMs and other consumer-facing tools, some of the greatest achievements in machine learning are outside the scope of these applications. For example, machine learning applications have made major contributions to computational biology. In that domain, the AlphaFold algorithms have implemented a model similar to the transformer to increase the number of all known protein structures in the world from $\approx 200,000$ to $\approx 2,000,000$ [4]–[6]. Just as some of the next decade's greatest achievements in biology and neuroscience will require applications of data science and machine learning, some of the greatest opportunities to innovate with data science and machine learning lie in applications to other sciences, including biology and neuroscience.

Deep neural network-based models–referred to here as artificial neural networks (ANNs)–are not the only technology showing promise for innovative applications to neuroscience. As neural tissue contains a network of connected, interacting neurons, known as a connectome, network science is similarly applicable. Network science provides a mathematical foundation for modeling connectomes, including excitatory, inhibitory, and modulatory relationships between neurons [7]–[11]. This foundation includes metrics (e.g., centrality, modularity) and algorithms (e.g., page rank and Louvain) for understanding individual nodes (neurons) and their communities within the network [8], [12], [13]. The foundation of network science is combined with ANNs in graph neural networks (GNNs), including graph autoencoders (GAEs), which involve convolutions on a product of the graph's adjacency matrix, degree matrix, and node feature embeddings to establish structure-aware embeddings of each node [14], [15]. As modern methodological advances increase capacity for collection of high-resolution connectomes, these network science tools are already beginning to be applied to improve understanding of nervous tissue function (e.g., [16], [17]).

This review considers the intersection of subfields in data science and neuroscience, including connectomics, brain computer interfaces, extracellular electrophysiology, neural signal processing, and spike train analysis. In introducing these subfields, I suggest that they have significant potential for synergy in accelerating understanding of microscale processing and distributed systems in the brain. In addition to providing understanding, I suggest that these same technologies will offer significant new clinical interventions for a wide variety of nervous system diseases and disorders over the next few decades.

A Connectome Details Neural Connections

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BCI Devices Enable Collection of Partial Functional Micro-Connectomes In-Vivo

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Extracellular Electrophysiology Optimizes Resolution and Coverage

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Scaled Electrophysiology Relies on Strong Neural Signal Processing

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Processing Spike Trains Produces a Functional Connectome

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Conclusion

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