Neuroscience

How Can We Map Our Brains?

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Understanding the human brain—arguably the most complex structure in the known universe—has long been a goal of science, medicine, and philosophy. Recent technological advancements have made the ambitious task of brain mapping more plausible than ever before. This essay explores the multidimensional approach needed to map the brain, emphasizing the roles of neuroimaging technologies, computational modeling, genetics, and artificial intelligence. It argues that while we are making rapid progress, truly mapping the human brain requires not just technical precision but also ethical mindfulness, global collaboration, and interdisciplinary innovation. Brain mapping is not only a scientific journey but also a humanistic one, requiring us to ask who we are and how our minds work.

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MAPPING the human brain is one of the greatest scientific challenges of our time. Like ancient explorers charting the seas, modern neuroscientists are navigating a vast, intricate, and largely uncharted territory—the terrain of the mind itself (Fox, 1993). But unlike mapping continents or even the genome, mapping the brain involves capturing dynamic, ever-changing processes that underlie thought, memory, sensation, emotion, and consciousness. So how can we map our brains? The answer lies in the convergence of several powerful scientific disciplines, from neuroimaging and genetics to artificial intelligence and computational modeling. Yet the challenges are not merely technical (Raichle, 2008). Mapping the brain also requires thoughtful engagement with ethical, philosophical, and social questions.

First, it's essential to understand what "mapping the brain" actually means. There are multiple levels of brain organization, including anatomical (structure), functional (activity), and connectomic (network connections) (Voigtlaender et al., 2024). Each of these layers offers a different "map" of the brain, and each requires different tools to explore. For instance, structural brain mapping seeks to chart the physical layout of the brain's regions and tissues—its gray and white matter, its folds and fissures (Collins et al., 2024). Functional brain mapping, on the other hand, looks at how regions of the brain activate in response to tasks, thoughts, or stimuli. This distinction highlights a core challenge: the brain is not a static organ. It is plastic, changing in response to learning, environment, and even injury (Tharin & Golby, 2024). Any effort to map it must therefore be able to account for not just structure, but activity and adaptability.

Perhaps the most recognizable tool in brain mapping is neuroimaging. Techniques like MRI (magnetic resonance imaging) and fMRI (functional MRI) have allowed us to peer into the living brain with unprecedented detail. MRI provides high-resolution images of brain anatomy, while fMRI measures changes in blood flow to infer brain activity (Khorev et al., 2024). Other techniques like PET (positron emission tomography) and MEG (magnetoencephalography) add further layers of functional insight (Tharin & Golby, 2024). Despite their contributions, neuroimaging methods have limitations. For example, fMRI's temporal resolution is poor compared to the millisecond-level activity of neurons. Moreover, these tools typically average data across time or across individuals, which can obscure individual variability or rapid brain dynamics (Chen et al., 2024). Thus, while neuroimaging provides a valuable starting point, it is not a complete solution.

One of the most promising new frontiers in brain mapping is connectomics—the study of the brain's wiring diagram. The Human Connectome Project, launched in 2009, has aimed to create a comprehensive map of neural connections in the brain (Elam et al., 2021). By combining diffusion tensor imaging (DTI) with advanced computational analysis, researchers have begun to visualize how different brain regions are interconnected (Sporns, 2013). The ultimate goal of connectomics is to generate a "connectome," or a complete map of neural pathways. Just as the Human Genome Project provided a blueprint of our DNA, the connectome could offer a blueprint of how the brain's structure supports mental function (Toga et al., 2012). However, generating a complete connectome, especially at the level of individual synapses, is a monumental task. For example, mapping a single cubic millimeter of mouse brain tissue required two petabytes of data and months of analysis (Oh et al., 2014).

Another vital piece of the puzzle is the role of genetics in brain organization and function. Brain development is heavily influenced by genetic instructions, and genetic variations are known to affect cognitive abilities, mental illness susceptibility, and personality traits (Puri et al., 2023). Techniques like single-cell RNA sequencing have made it possible to identify the genetic expression profiles of individual brain cells, helping us to classify brain cell types with increasing specificity. The Allen Brain Atlas, for example, is a comprehensive resource that maps gene expression in the brain and integrates it with anatomical and functional data (Ball et al., 2012). Understanding how genes influence brain development and function deepens our map and links molecular biology with systems neuroscience.

Artificial intelligence (AI), particularly deep learning, is playing a transformative role in brain mapping. AI algorithms can process massive volumes of neuroimaging data far faster and more accurately than humans. For instance, convolutional neural networks have been used to detect subtle patterns in brain scans that may predict diseases like Alzheimer's years before symptoms appear (Fiani et al., 2021). In addition to analyzing data, computational neuroscience aims to build models of the brain that replicate its function (Noor et al., 2020). These simulations—whether of a single neuron or an entire brain region—help researchers test hypotheses, understand system behavior, and even reverse-engineer certain processes. Projects like the Blue Brain Project and the Human Brain Project in Europe aim to create comprehensive digital reconstructions of the brain's architecture and function (Amunts et al., 2019).

While the technological possibilities are staggering, brain mapping also raises profound ethical questions (Frackowiak & Markram, 2015). Who owns the data generated by brain scans? How do we protect privacy when neural data could, theoretically, reveal thoughts or intentions? Moreover, how do we ensure that such powerful tools are used to benefit all of humanity, and not just a privileged few? There are also philosophical dimensions to consider. If we succeed in mapping the brain down to the last synapse, will we understand consciousness? Or is there something inherently subjective—something irreducible— about the mind? Some argue that no matter how detailed our map, the "hard problem" of consciousness—the question of how subjective experience arises—may remain unsolved.

The complexity of the human brain demands an integrative approach. No single technology or discipline can capture the full richness of the brain (Gierer, 2008). Instead, we must combine multiple types of data—structural, functional, genetic, and behavioral—into unified models. Such an endeavor will require unprecedented collaboration between neuroscientists, engineers, computer scientists, ethicists, and philosophers. One promising direction is the use of multimodal brain mapping, which layers data from different sources to provide a richer, more comprehensive view (Uludağ & Roebroeck, 2014). For example, combining fMRI with EEG (electroencephalography) can offer both high spatial and high temporal resolution. Likewise, integrating genetic and imaging data may reveal how specific mutations affect brain function and behavior (Loosen et al., 2024).

In sum, mapping the brain is more than a technical exercise—it is a journey into the essence of what makes us human. As we chart this vast and intricate organ, we are also confronting profound questions about identity, thought, and consciousness. The tools we use—from MRI scanners to machine learning algorithms—are remarkable, but they are only part of the story. To truly map our brains, we need to approach the task with not only scientific rigor but also imagination, humility, and ethical clarity. The brain is not just an object to be mapped—it is the seat of experience, creativity, memory, and love. As such, the endeavor to map it must reflect not only our scientific ambition but also our human values.■

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References

Amunts, K., Knoll, A. C., Lippert, T., Pennartz, C. M. A., Ryvlin, P., Destexhe, A., Jirsa, V. K., D'Angelo, E., & Bjaalie, J. G. (2019). The Human Brain Project—Synergy between neuroscience, computing, informatics, and brain-inspired technologies. PLoS Biology, 17(7), e3000344. https://doi.org/10.1371/journal.pbio.3000344

Ball, S., Gilbert, T. L., & Overly, C. C. (2012). The Human Brain Online: An open resource for advancing Brain research. PLoS Biology, 10(12), e1001453. https://doi.org/10.1371/journal.pbio.1001453

Chen, J., Yu, K., Bi, Y., Ji, X., & Zhang, D. (2024). Strategic Integration: A Cross-Disciplinary review of the FNIRS-EEG Dual-Modality Imaging System for delivering multimodal neuroimaging to applications. Brain Sciences, 14(10), 1022. https://doi.org/10.3390/brainsci14101022

Collins, E., Chishti, O., Obaid, S., McGrath, H., King, A., Shen, X., Arora, J., Papademetris, X., Constable, R. T., Spencer, D. D., & Zaveri, H. P. (2024). Mapping the structure-function relationship along macroscale gradients in the human brain. Nature Communications, 15(1). https://doi.org/10.1038/s41467-024-51395-6

Elam, J. S., Glasser, M. F., Harms, M. P., Sotiropoulos, S. N., Andersson, J. L., Burgess, G. C., Curtiss, S. W., Oostenveld, R., Larson-Prior, L. J., Schoffelen, J., Hodge, M. R., Cler, E. A., Marcus, D. M., Barch, D. M., Yacoub, E., Smith, S. M., Ugurbil, K., & Van Essen, D. C. (2021). The Human Connectome Project: A retrospective. NeuroImage, 244, 118543. https://doi.org/10.1016/j.neuroimage.2021.118543

Fiani, B., Pasko, K. B. D., Sarhadi, K., & Covarrubias, C. (2021). Current uses, emerging applications, and clinical integration of artificial intelligence in neuroradiology. Reviews in the Neurosciences, 33(4), 383–395. https://doi.org/10.1515/revneuro-2021-0101

Fox, P. T. (1993). Human brain mapping: A convergence of disciplines. Human Brain Mapping, 1(1), 1–2. https://doi.org/10.1002/hbm.460010102

Frackowiak, R., & Markram, H. (2015). The future of human cerebral cartography: a novel approach. Philosophical Transactions of the Royal Society B Biological Sciences, 370(1668), 20140171. https://doi.org/10.1098/rstb.2014.0171

Gierer, A. (2008). Brain, mind and limitations of a scientific theory of human consciousness. BioEssays, 30(5), 499–505. https://doi.org/10.1002/bies.20743

Khorev, V., Kurkin, S., Badarin, A., Antipov, V., Pitsik, E., Andreev, A., Grubov, V., Drapkina, O., Kiselev, A., & Hramov, A. (2024). Review on the use of Brain Computer Interface Rehabilitation Methods for treating mental and Neurological Conditions. Journal of Integrative Neuroscience, 23(7). https://doi.org/10.31083/j.jin2307125

Loosen, A. M., Kato, A., & Gu, X. (2024). Revisiting the role of computational neuroimaging in the era of integrative neuroscience. Neuropsychopharmacology, 50(1), 103–113. https://doi.org/10.1038/s41386-024-01946-8

Noor, M. B. T., Zenia, N. Z., Kaiser, M. S., Mamun, S. A., & Mahmud, M. (2020). Application of deep learning in detecting neurological disorders from magnetic resonance images: a survey on the detection of Alzheimer's disease, Parkinson's disease and schizophrenia. Brain Informatics, 7(1). https://doi.org/10.1186/s40708-020-00112-2

Oh, S. W., Harris, J. A., Ng, L., Winslow, B., Cain, N., Mihalas, S., Wang, Q., Lau, C., Kuan, L., Henry, A. M., Mortrud, M. T., Ouellette, B., Nguyen, T. N., Sorensen, S. A., Slaughterbeck, C. R., Wakeman, W., Li, Y., Feng, D., Ho, A.,. Zeng, H. (2014). A mesoscale connectome of the mouse brain. Nature, 508(7495), 207–214. https://doi.org/10.1038/nature13186

Puri, S., Shaheen, M., & Grover, B. (2023). Nutrition and cognitive health: A life course approach. Frontiers in Public Health, 11. https://doi.org/10.3389/fpubh.2023.1023907

Sporns, O. (2013). The human connectome: Origins and challenges. NeuroImage, 80, 53–61. https://doi.org/10.1016/j.neuroimage.2013.03.023

Tharin, S., & Golby, A. (2007). Functional brain mapping and its applications to neurosurgery. Operative Neurosurgery, 60(4), 185–202. https://doi.org/10.1227/01.neu.0000255386.95464.52

Toga, A. W., Clark, K. A., Thompson, P. M., Shattuck, D. W., & Van Horn, J. D. (2012). Mapping the human connectome. Neurosurgery, 71(1), 1–5. https://doi.org/10.1227/neu.0b013e318258e9ff

Uludağ, K., & Roebroeck, A. (2014). General overview on the merits of multimodal neuroimaging data fusion. NeuroImage, 102, 3–10. https://doi.org/10.1016/j.neuroimage.2014.05.018

Voigtlaender, S., Pawelczyk, J., Geiger, M., Vaios, E. J., Karschnia, P., Cudkowicz, M., Dietrich, J., Haraldsen, I. R. J. H., Feigin, V., Owolabi, M., White, T. L., Świeboda, P., Farahany, N., Natarajan, V., & Winter, S. F. (2024). Artificial intelligence in neurology: opportunities, challenges, and policy implications. Journal of Neurology, 271(5), 2258–2273. https://doi.org/10.1007/s00415-024-12220-8