THE BRAIN ARK: BRAIN CONNECTOME PROPERTIES OF TERRESTRIAL INTELLIGENCE AS A METRIC FOR EXTRATERRESTRIAL INTELLIGENCE. Gregory S. Berns[1], [1]Emory University (Psychology Department, 36 Eagle Row, Atlanta GA 30322. Email: gberns@emory.edu)

Overall Goal(s) and Objective(s):
Use neuroimaging tools to construct the connectome of a wide variety of terrestrial brains to determine the level of connection complexity that supports different levels of sentience and intelligence. Such metrics could be applied to extraterrestrial systems, including both biological and nonbiological architectures.

Background

Techniques in neuroscience, especially imaging, have advanced at a remarkable rate. With MRI, we can now image the brain at submillimeter resolution without even cutting into it, and specialized imaging sequences, like diffusion tensor imaging (DTI), allow for the digital reconstruction of white matter pathways *in situ*. With this information, one can then determine how different brain regions are connected to each other, providing a blueprint of the brain's functional architecture. These techniques have become standard fare within the human neuroimaging field and have begun to reveal structural differences in a variety of CNS disorders.

Despite the advances in neuroimaging tools, they have not been widely applied to the brains of non-human animals. Apart from humans, non-human primates, rats and mice, almost no information exists about the connectivity of other species' brains. For example, what is it in a tiger's brain that makes it a tiger? Or in a bear's brain that makes a bear? The relationship between brain and species is fundamental to understanding the evolution of the nervous system, and can illuminate sensory, motoric, and cognitive adaptations that help situate each species in its ecological niche.

Relevance to SETI

Potential relevance to SETI is in the characterization of informational metrics of nervous systems that would be indicative of sentience and intelligence. Since there is presently no knowledge about extraterrestrial life forms, we must look to the wide variety of terrestrial life for characteristics that might, indirectly, define 'intelligence.' But rather than define intelligence strictly on behavioral or intellectual criteria, which suffer from anthropomorphic biases, we suggest looking to attributes of brains that can support a level of functional complexity that might be foundational for intelligent life, in any form.

One theory suggests that as brains get bigger they become more modularized [1,2]. The assumption is that as brains get bigger, the number of connections necessary to link neurons grows exponentially, but because a brain is physically constrained by body size and skull morphology, the maintenance of full inter-regional connectivity is not possible, and the brain breaks into modules. With new imaging tools and advances in network science, we can now test these ideas for the first time. The results will have ramifications beyond evolutionary biology, including constraints on information processing (biological and artificial) and the necessary level of complexity indicative of intelligent life.

Specifically, we hypothesize, across a wide range of mammalian species:

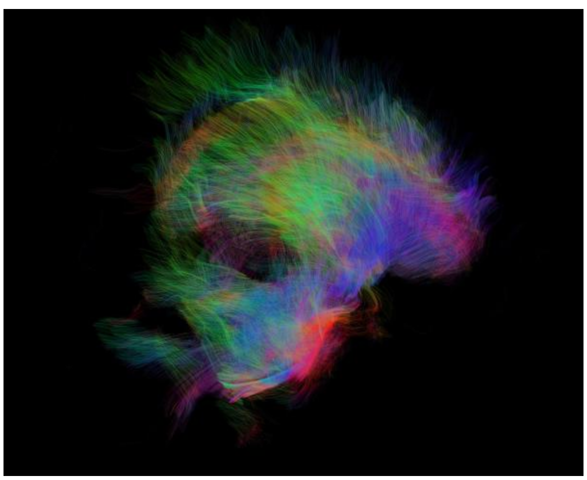
- The overall modularity of the cortex follows a scaling law with brain size. The optimal network structure is a subdivision of the network into nonoverlapping groups of regions in a way that maximizes the number of within-group edges (connections between regions), and minimizes the number of between-group edges. The modularity is a statistic that quantifies the degree to which the network may be subdivided into such clearly delineated groups [3]. We will test how modularity changes with brain size (modularity quotient).
- Deviations from the modularity quotient will be dictated by ecological niche and intelligence. For example, carnivores are hypothesized to have more complex brain networks and would be predicted to have higher modularity (and intelligence) than similarly sized herbivores.
- Beyond modularity, we hypothesize that cortico-thalamic patterns of connectivity can identify analogous brain regions across a wide range of species. Identification of analogous brain regions is critical for mapping how modules move under evolutionary pressure.

Approach

We are using diffusion tensor imaging (DTI) to map the three-dimensional structure of white matter pathways in mammalian brains across a wide-range of taxa. The Brain Ark will be more than a collection of structural MRIs. The Ark will contain three-dimensional reconstructions of the white-matter pathways of each taxon. The data will be in sufficient detail so that we can virtually probe how regions are connected to each other and therefore answer questions about brain evolution, or how brain structure is related to species-specific attributes like predator/prey, ecological niche, foraging strategies, and sexual dimorphisms.

DTI will be acquired using a sequence optimized for postmortem tissue [4] at a minimum of 1 mm resolution. This sequence is more efficient than standard spin-echo sequences and has demonstrated good SNR in tissue even a century old [5,6]. The DTI data will be processed using standard imaging tools, with the end result being a set of distributions of diffusion values at each voxel necessary for running probabilistic models of tractography. Tractography will then be used to calculate measures of modularity.

To create a Brain Ark, we will need to assemble a consortium of scientists with access to MRI facilities, and zoos and animal parks with brain specimens. Because MRI is non-invasive, there is no need to cut into any specimen. And, once scanned, specimens will be returned to their place of origin. Although we have scanned specimens more than a decade old (and even some more than a century old!), fresher is better. Therefore, the consortium will also establish an alert network for the preservation and scanning of the brains of animals upon their death.



What's possible: 3D-reconstruction of the white matter pathways in the brain of a common dolphin.

Additional Information:

(A) Which Question(s) of the *Alien Mindscape* article is your white paper is relevant to? See conclusion, page 671: http://online.liebertpub.com/doi/pdf/10.1089/ast.2016.1536

Question 2: How does intelligent life communicate? Connectome data from terrestrial brains can provide the roadmap for the type of system that can support intelligence.

(B) How Big Data Analysis can help you advance this project/concept (and which datasets/databases)?

Presently there is no principled way to compare the brains of different species. Brains come in different shapes and sizes. We need big data and machine learning approaches to identify the similarities and differences in the connectome space.

References

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