The Fractal Brain

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Is the brain self-similar, or fractal?

The complexity of human brain geometry suggests a description based on fractality, a mathematical construction to describe self-similarity in various objects in dead and living matter. This would mean that properties or patterns of small cortex structures would be equal to larger ones. Topology is another character. That is the possibility to recognize different forms in smaller, as well as in larger areas, thou somewhat tortoised. This picture refers to average picture of function and structure in brain, not detailed anatomy or fysiology.

Fractal brain, fractal art. It looks like the brain is made of energy, and that energy is shooting outwards from the brain.

During 1990-decade several authors found fractal geometry of brain highly probable. Surface-to volume ratio, external cortex surface, 3-D analysis of fixed brains, interface between grey and white matter, etc. From these it seems that white matter has indeed a fractal geometry, but perhaps not including all the brain. In neuroscience, researchers have examined the structure of axonal networks connecting individual neurons and whole-brain networks of interregional pathways.
Verification is needed.

The geometry of human cortical grey matter was the subject for Kiselev 2008. Analysis including all spatial scales from size of the brain to the ultimate image resolution showed fractality down to scale size 2,5 mm, corresponding to the cortex thickness. Also the folding of the brain shows fractality for the largest spatial scales. Note that two individuals are never identical, nor has cortex the same thickness everywhere. The foldings can be described as dilations, showing different characteristics for inner and outer surfaces of cortex. Averages may show errors. As a whole fractality exists in both area and volume of the brain.

There is also a possibility for correlations with brain deseases.

Brain function.
Brain function depends on adaptive **self-organization** of large-scale neural assemblies, but little is known about quantitative network parameters governing these processes in humans. Here, the topology and synchronizability of frequency-specific brain functional networks.
Brain functional networks were characterized by small-world properties at all six wavelet scales considered, corresponding approximately to classical δ (low and high), θ, α, β, and γ frequency

bands. Global topological parameters (path length, clustering) were conserved across scales, most consistently in the frequency range 2–37 Hz, implying a scale-invariant or fractal small-world organization. Dynamical analysis showed that networks were located close to the threshold of order/disorder transition in all frequency bands. The highest-frequency γ network had greater synchronizability, greater clustering of connections, and shorter path length than networks in the scaling regime of (lower) frequencies. Behavioral state did not strongly influence global topology or synchronizability; however, motor task performance was associated with emergence of long-range connections in both β and γ networks. Long-range connectivity, e.g., between frontal and parietal cortex, at high frequencies during a motor task may facilitate sensorimotor binding.

Human brain functional networks demonstrate a fractal small-world architecture that supports critical dynamics and task-related spatial reconfiguration while preserving global topological parameters.

The small-world topology of brain functional networks is largely preserved across multiple frequency bands and behavioral tasks. The canonical small-world network is one in which the majority of edges are recruited to form small, densely connected clusters, whereas the remainder are involved in maintaining connections between these clusters.

Patterns of functional connectivity across a large number of recording sites were obtained for each of six distinct temporal scales **ranging over all classical EEG frequency bands**, from low (1.1–2.2 Hz) to gamma (37.5–75 Hz). These correlations between signals in wavelet space express a statistical association between recording sites, a signature of dynamical interactions between brain regions. The authors then transform the continuous symmetric matrix of wavelet correlations obtained for each frequency band to a binary symmetric matrix by applying a threshold

Small-world attributes reflect the need of the network to satisfy simultaneously the opposing demands of local and global processing and that they may reflect an organization that tends to minimize the number of processing steps. Given the spatial complexity of neural dynamics, it seems likely that functionally relevant communication would have to occur across multiple frequency bands. Correlations to EEG - EMG - EXG ??? If the small-world functional architecture revealed by Bassett et al. indeed promotes efficient interregional communication, then it should be found across multiple temporal scales.

It appears that brain networks preserve global topological characteristics (continually maintaining the balance of efficient local and global processing) while flexibly adapting the specifics of the topology to satisfy changing task demands. Interestingly, it appears that higher-frequency bands (beta and gamma) exhibit more extensive changes in connection patterns across tasks, specifically in the form of new long-range functional relationships between sensory and motor regions during the execution of a motor task.

The idea that perception and cognition depend critically on patterns of synchronization and desynchronization, fits perfectly in this picture. The dynamic coupling and uncoupling of distant neural sites reflect changes in sensory inputs, task demands, thinking or attention. The fact that these synchronization patterns occur at multiple frequencies might mean that brain functional networks contain multiple ‘‘frequency channels’’ along which information is transmitted. What happens when the global topology of human brain functional networks changes across all frequency bands or within a specific range of frequencies. Empirical evidence suggests that such changes in global network topology occur between sleep and waking.

Is form a reason for function?
Can function be revealed by structure? This is an old question, not yet answered. In brain we have Broadmanns areas that certainly suggest functions. A small-world network has been suggested to be an efficient solution for achieving both modular and global processing—a property highly desirable for brain computations.

Functional connectivity has previously been shown to correlate with structural (anatomical) connectivity patterns at an aggregate level.
1.strong functional connections commonly exist between regions with no direct structural connection, rendering the inference of structural connectivity from functional connectivity impractical;
2. indirect connections and interregional distance accounted for some of the variance in functional connectivity that was unexplained by direct structural connectivity;
3. resting-state functional connectivity exhibits variability within and across both scanning sessions and model runs.

These empirical and modeling results demonstrate that although resting state functional connectivity is variable and is frequently present between regions without direct structural linkage, its strength, persistence, and spatial statistics are nevertheless constrained by the large-scale anatomical structure of the human cerebral cortex.

Self-organization is a inherent principle in brain and in whole universe? This question links to the traditional chinese medicine (Yin and Yang) and the entropy model of body/mind/brain.

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Small worlds inside big brains.

Luke Gardiner by deviantART. http://rustkill.deviantart.com/art/Fractal-Brain-7070062 Fractal brain, fractal art
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