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Fractal Brains: Fractal Thoughts

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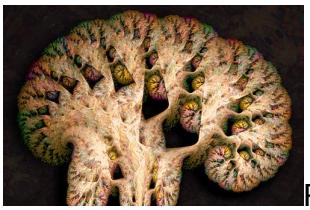 Researchers from the University of Cambridge took a big step forward this year in understanding how our brains work. It seems that the brain has a fractal organization. This likely gives us much of what we consider human. And at a deeper level these findings may help to connect us in a very fundamental way to the rest of the natural world.

The research team of Kitzbichler, Smith, Christensen, and Bullmore published their results in an article called "Broadband Criticality of Human Brain Network Synchronization," which is available on-line for free (see link below). I've had the article for about six months and had been meaning to post something on it. So at the outset I'd like to thank "Neel" for getting me going to actually re-read the article and post something with an interesting question he posed about neurological complexity and intelligence to the Chaotic Life blog at Psychology Today last month. I'd also like to thank my friend and colleague from NY, Grant Brenner for alerting me to the article when it first came out.

The design, results and context for this study are very sophisticated, and the implications are quite abstract. So I'm going to do my best to be clear. First the context: Many natural systems exhibit fractal organization and behavior. A fractal is a branchlike structure. Think of a tree: (1) Trees have many more small branches than large ones. This characteristic is also sometimes called a "power-law" or "inverse power law" or a "1/f" organization. Each of these terms means that there are exponentially more small branches compared to big ones. (2) Trees are "self-similar," meaning that small branching patterns resemble larger ones. This characteristic is also sometimes called "scale invariance" or "scale free" because no matter the size you are looking at, the general branching shape is the same. (3) The complexity of tree branching patterns can be quantified. Fractals are called "fractals" because they exist in fractional dimensions. A line fits perfectly in one-dimension. A plane (like a piece of paper) fits in two-dimensions. Fractals fit in between a line and a plane (or in the real world between two and three dimensions). More simply, because they are so complex, with huge numbers of tini tiny branches, trees never quite reach three dimensions. If you put them in a box, there will always be some space left over.

You may quickly recognize that many other natural structures besides trees are fractals: Neurons, rivers, the respiratory system, the circulatory system, geological fault lines, snow-flakes, and so on.

Natural systems also produce fractal behavior over time or in dynamics. Earthquakes are a common example. There are many more small earthquakes than large ones (which is nice by the way). Other examples include the size of extinction events in

animal species, numbers of academic publications (a few researchers do huge amounts of work and the rest of us do just a little), numbers of hits to web-sites, wait times in stop-and-go traffic, and word usage in literature (i.e., zipf's law).

Why do systems do this? There are many reasons. Essentially, fractal systems have many opportunities for growth, change and re-organization. Yet they also are very robust. They maintain their coherence; they hold together well, even under tough circumstances. They are balanced in this respect, between order and chaos. They are simple, yet also very complex. This balance is often referred to as "criticality," thus the title of the article: "Broadband Criticality." And the term "self-organized" is often added because systems tend to become fractal on their own, simply by putting a lot of system components together and allowing them to exchange information. Think of a party. All you need to do is come up with enough people at the same place and time and they will start to form complex patterns of connection with one another.

Self-organizing critical systems are also very good at connecting, both internally and also to other surrounding systems. The branches of a tree are connected in a very lovely way. If you shake one branch, you'll see broad shaking across the tree. Fractal structures hang together nicely. Yet they branches may be trimmed without effecting the overall structure. Indeed, if you trim them far enough out (above the growth bud, "post-traumatic growth" or "whatever doesn't kill you makes you stronger") they will often grow even stronger, with more complex connections in the outer branches. Finally, branchlike patterns easily connect to other systems - a literal web of life. A tree with many fractal branches (and also roots) can better connect to the sun (and soil) to gather and exchange life sustaining nutrients.

In the past 10 to 20 years, researchers in psychology have been finding increasing examples of fractal patterns across each of the domains of psychology: Including intentional behaviors, visual search, and speech patterns. In my own lab within the past few years we have found that interpersonal relationships are organized as fractals and most recently that the self-concept is a fractal, with complexity being associated with health in both the psychological and social domains. Furthermore, it appears that fractal complexity (or rigidity) is routinely exchanged among biological, psychological and social processes. Fractal personality structure helps us to grow and connect, as do fractal relationships, and each likely has direct influences on physical health by encouraging integration and flexibility among circulatory, respiratory, and immune systems.

The study by Kitzbichler et al (2008) has added to much prior research suggesting that the brain exhibits fractal behavior. This makes a necessary link between the physical processes of the brain and each of the larger scale fractals we see in broader personality and social relationships. It is clear that biological, psychological and social dynamics are highly interlinked across scales, each impacting the other over time in myriad ways. With fractal organization at each of these scales, one may propose that they in some respects they are all part of the same fractal tree so to speak.

Kitzbichler et al (2008) used two measures of synchronization across brain systems: (1) the "phase-lock interval" and the "lability of global synchronization." The phase-lock interval is the amount of time that different brain regions are doing the same thing together - the amount of time in which they are synchronized. Essentially, this is a time-based measure of brain system coordination. The other measure, "lability of global synchronization" is a space-based measure. This measure tells you how global are the shifts in brain system synchronization, how broad are they, how far reaching.

Leaving out the many wonderful technical details of their analyses, they found that both measures showed clear-cut fractal patterning. This means that the amount of time that different brain regions spend in sync is branchlike - with many short linkage times and fewer long ones. And the spread of these linkages across brain regions was branchlike too, with many small spreads and few large ones.

These results, along with the evidence that has come before them, provide a much truer picture of how the brain is organized and how it works. Such is the core of basic research. The applications of these results may be considered to be virtually unlimited, and will over time impact every branch of applied neuroscience - intelligence, consciousness, empathy, body-mind medicine, psychiatry and psychotherapy.

What I would prefer to speculate upon instead would be the broader implications. Indeed what these robust results within the brain suggest is a possible mechanism for the "Broadband Connectivity" we share with the rest of the natural world. Inasmuch as fractal dynamics in broadband synchronization exist at every scale of measurable reality - from quantum to cosmic, perhaps human consciousness is both simply and profoundly a portal through which such fractal connectivity flows. Perhaps the linkages that so effect our growth and integration at the biopsychosocial scales extend much deeper into the roots of matter, and much farther into the cosmos than modernist science has ever imagined. Science appears to be nearing a period of neo-vitalism, with scientifically grounded ways of exploring the attractive worldview of our root-civilizations - that everything in life is connected and that all of the universe is alive within these connections.

Sure - some connections are more proximal than others. Kitzbichler et al. found that functionally connected brain regions were more likely to find and stay in sync with one another for longer periods of time, yielding fractal complexity measures that were less flexible than the connections among more distant regions. Similarly, one's life-partner will be more likely to drive you crazy than the moon.

Nevertheless, it will be interesting to see if certain systemic states encourage coherence, magnifying the connections among apparently separate systems. For example, the human stress response is a likely candidate for increasing the short-term coherence among biological, psychological and social processes. When you are stressed, your bodily systems band together, your psychological systems become clear and focused, and your social dynamics become coherent as well as you band together and form strict leadership hierarchies. Does human stress have broader impacts? Can their effect be measured even as far as the quantum realm? Conversely, can quantum systems become "stressed" leading them to reach into our macro world? Maybe so, maybe not. One thing is for sure, this blog is already way to long and abstract to fully consider these possibilities. Perhaps another day..?

Link to article: http://www.ncbi.nlm.nih.gov/pubmed/19300473?ordinalpos=14&itool=EntrezSystem2.PEntrez.Pubmed.Pubmed_ResultsPanel.Pubmed_D

Links:
[1] http://www.psychologytoday.com/blog/the-chaotic-life