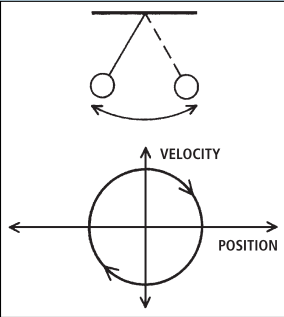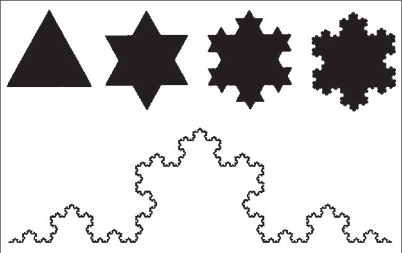## The Dynamics of Consciousness


When the velocity and position of a pendulum are plotted in 2D, the data are bound in a single point moving through phase space. The dynamics are "pulled" towards the circular ATTRACTOR.

Complex systems like the weather may be governed by nonlinear dynamics (NLD). NLD attractors are FRACTALS (fraction of a dimension). Fractal shapes, like the Koch snowflake and curve shown above (1.26 dimensions) display self-similarity at different scales. The brain exhibits NLD.

▲ Fractal shapes occur throughout nature, as in these Romanesco cauliflowers.

14 sec of human EEG embedded in 3D
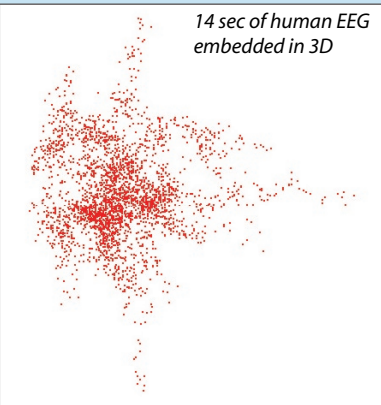
▲ Fractal shapes may be discerned in 3D plots of the EEG. The fractal dimension in phase space correlates approximately to the number of variables in the NLD system.

400 msec of human EEG embedded in 3D; data points connected
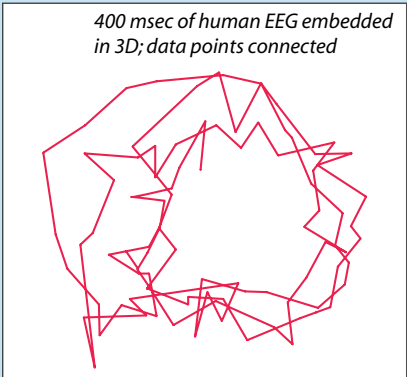
◄ In NLD systems, data synthesis remains bound at a single point moving through multidimensional phase space. Measurement of the number of dimensions correlates to the variables in the system. Thus, NLD measurements offer a window through which to observe the binding required for consciousness.

A Possible Evolutionary Pathway to Consciousness

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INTRODUCTION

Purposeful movement may have evolved from coordinate transformations between sensory phase space and motor phase space (1). If awareness evolved to facilitate sensory-motor coordination, evidence of its appearance may be sought in the phase space of surviving species (2).

Examination of the brain's nonlinear dynamics allows observation and dimensional estimation of the associated strange attractors which are testaments to the underlying synthesis and binding of information thought to be necessary for the development of consciousness. Animals may be used as surrogates for their distant ancestors. Skull fossils and brain endocasts support the theory that surviving species' brains are virtually unchanged from those of their fossilized predecessors, at least back to the time of evolutionary diversification.

METHODS

Animals observed included anemone, starfish, earthworm, clam, crayfish, lobster, minnow, perch, catfish, toad, frog, turtle, bird, opossum, cat, dog, horse, goat and human. A Grass Model 8-10B electroencephalograph with two-channel montage and surface electrodes was used. Bandpass was set between 0.1 and 70 Hz. Signals were digitized at 240 bits per second using a DI 194 data acquisition card (Dataq Instruments), then stored on CDs for later analysis. Using the Nonlinear Dynamics Toolbox (correspondence, Reiss@qmul.ac.uk, 2002), the data were examined by delay coordinate embedding. The dimension of any underlying strange attractor was expressed as the *correlation dimension* (D2). The highest calculated dimension of the strange attractor in phase space was plotted against the best estimate for time of diversification.

RESULTS

The anemone and starfish showed no signs of higher dimensional strange attractors to indicate the presence of underlying nonlinear dynamics. The remaining fauna's EEGs exhibited underlying nonlinear dynamics (see Table). The data show a steady increase in attractor dimension during the past billion years.

Animal	Time Since Divergence (Billion years)	EEG Correlation Dimension (D2)
Anemone	0.81	1
Starfish	0.8	1
Worm	0.7	1.64
Clam	0.65	1.89
Crayfish	0.65	1.98
Lobster	0.65	2.1
Perch	0.5	2.15
Catfish	0.5	2.43
Minnow	0.5	2.94
Toad	0.32	2.93
Frog	0.32	3.41
Turtle	0.22	3.33
Bird	0.155	3.48
Possum	0.125	3.82
Cat	0.07	4.61
Dog	0.064	4.73
Goat	0.053	4.46
Horse	0.053	4.61
Human	0.005	4.7

EEG Fractal Dimension Estimation (D2) versus Time Since Divergence
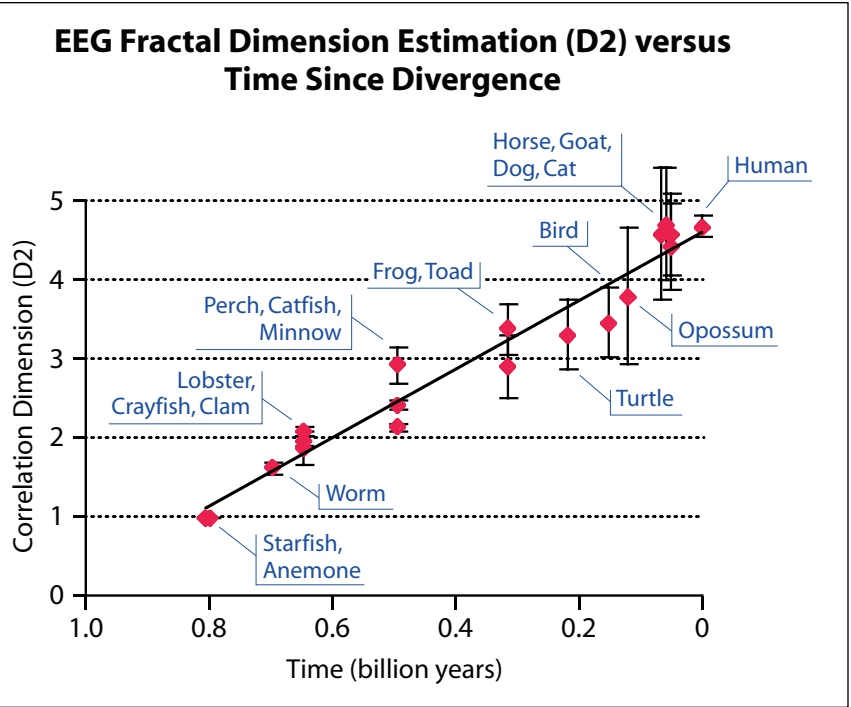
CONCLUSIONS

■ We show an approximate increase in the dimension of the strange attractor of one per 250,000,000 years.

■ The more variables that contribute to a nonlinear dynamical system, the greater are the number of dimensions in phase space which are needed to accommodate them. As dimensions increase, data synthesis remains bound in a point moving through phase space.

■ Increasing dimensions during evolution improve the ability to synthesize and bind the information necessary to achieve consciousness, and represent a natural progress up the scaffolding of existing mathematical order.

■ Strange attractors in phase space may offer a repository for the compression and synthesis of data and a "place" for consciousness. Such a HYPERSPACE could help explain binding and may describe how the contents of our visual consciousness seem to be outside of our heads!

REFERENCES

1. Churchland PS. *Neurophilosophy: Towards a Unified Science of the Mind-Brain*. Cambridge, Mass: MIT Press, 1986:420–423.

2. Walling PT, Hicks KN. Dimensions of consciousness. *BUMC Proceedings* 2003;16:162–166 (http://www.baylorhealth.com/proceedings/16_2/16_2_walling.pdf).

Addendum

Walling-Hicks Hypothesis
Nonlinear Dynamics (NLD) and Consciousness

NLD is represented by a single point moving through phase space;

NLD is characterized by strange attractors in phase space;

NLD attractor dimensions increase to accommodate more variables;

NLD attractors represent data drawn to higher-dimensional phase space;

NLD is nonlocal, data is bound in phase space.

Consciousness involves nonlocal binding of data;

NLD may be observed in EEG data originating from the brain;

NLD attractors appeared during the evolution of the brain;

NLD attractor dimensions correlate with evolutionary ranking;

NLD attractor dimensions correlate with the human EEG recorded during different mental tasks;

Therefore, NLD attractors may be repositories of the data necessary for consciousness and windows through which the working of the brain may be observed. Attractors may be seen as multidimensional graph paper enabling a single point to plot several functions at once.

Thus, in NLD we find the sign to bind the mind!