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Review Article

Application of a Time-Delay Model of the Plykin - Newhouse Attractor to Study the Dynamics of Neuro - Degeneration by Electroencephalography of the Brain

Sergey Belyakin[1*], Sergey Shuteev[1]

[1] Physics Faculty, Department of General Physics, Lomonosov Moscow State University, Moscow, Russia.

Corresponding Author: Sergey Belyakin, Physics Faculty, Department of General Physics, Lomonosov Moscow State University, Moscow, Russia.

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Abstract:

Neurodegeneration is the progressive loss of structure or function of neurons, which may ultimately involve cell death. Many neurodegenerative diseases-such as amyotrophic lateral sclerosis, multiple sclerosis, Parkinson's disease, Alzheimer's disease, Huntington's disease, and prion diseases-occur as a result of neurodegenerative processes. Neurodegeneration can be found in the brain at many different levels of neuronal circuitry, ranging from molecular to systemic. Because there is no known way to reverse the progressive degeneration of neurons, these diseases are considered to be incurable. Biomedical research has revealed many similarities between these diseases at the sub-cellular level, including atypical protein assemblies (like proteopathy) and induced cell death. These similarities suggest that advances against one neurodegenerative disease might ameliorate other diseases as well. In this report, an autonomous physical system is used, which is represented by a Smale Williams hyperbolic type attractor. Dynamics and evolution of neurodegeneration The Plykin-Newkhoz attractor model with the Piragas method is applied [1-10].

Keywords: neurodegeneration, neurons, chaotic dynamic, the attractor of the plykin - newhouse, method of pyragas, hyperbolicity

1. Introduction

In mathematical theory of dynamical systems a class of *uniformly hyperbolic strange attractors* is known. In such an attractor all orbits are of the same saddle type, they manifest strong stochastic properties and allow detailed theoretical analysis. In textbooks and reviews, examples of these attractors are traditionally represented by abstract artificial constructions like the Plykin attractor and the Smale - Williams attractor. The simplest attractor of Plykin type is constructed with mapping of a domain of a plane with holes into itself. To construct a system with the Plykin attractor let us start with a map of a unit sphere defined as a sequence of four periodically repeating stages of continuous transformations. Duration of each stage is taken to be equal to a unit time interval. The holes will correspond to neighborhoods of four points A, B, C, D on the spere. Let us define the first stage as a flow of the representative points along circles of lattitude away from the meridians AB and DC. The second stage is differential rotation around z-axis with angular velocity depending on z linearly, in such way that the points B and C do not move, while the points A and D exchange their location. The third and the fourth stages are similar to the prevous two, but differ in the spatial orientation: the axes x and z exchange their roles. The fig.1 illustrates the the transformations geometrically, and differential equations for all the stages are written down [11].

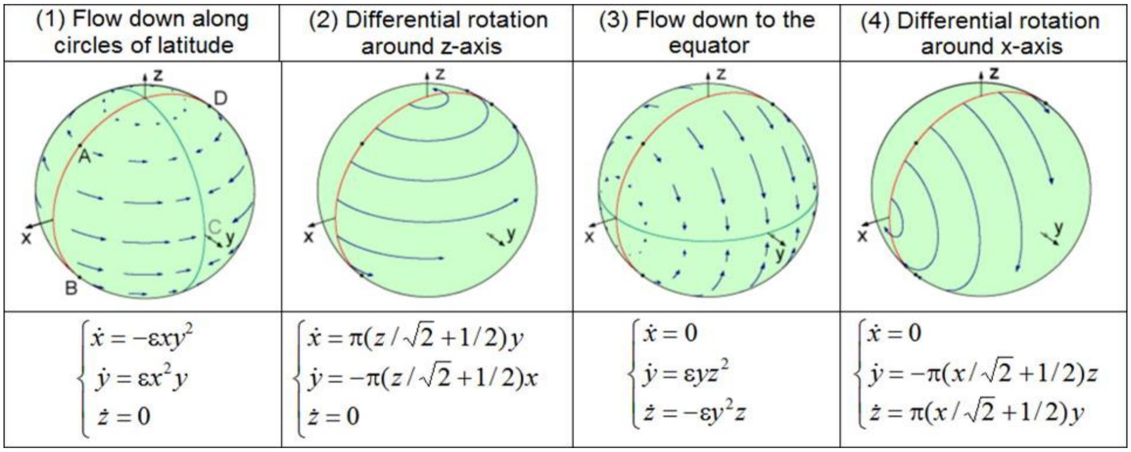

Figure 1. *Implementation of an Smale - Williams attractor on a sphere, the Plykin - Newhouse attractor.*

2. Hyperbolic Plykin - Newhouse attractor on a spherical surface

The realization of an Hyperbolic Plykin - Newhouse attractor on a sphere is represented by the equation [12] (1).

$$\begin{aligned}
\dot{x} &= \pi y\left(\tfrac{\sqrt{2}}{2}z+\tfrac{1}{2}\right)-\varepsilon xy^2,\\
\dot{y} &= -\sqrt{2}\pi zx-\tfrac{1}{2}\pi\left(x+z\right)+\varepsilon y\left(x^2+z^2\right),\\
\dot{z} &= \pi y\left(\tfrac{\sqrt{2}}{2}x+\tfrac{1}{2}\right)-\varepsilon zy^2,\\
1 &= x^2+y^2+z^2.
\end{aligned} \tag{1}$$

The realization of an Hyperbolic Plykin - Newhouse attractor on a sphere is represented by figure 2, figure 3.

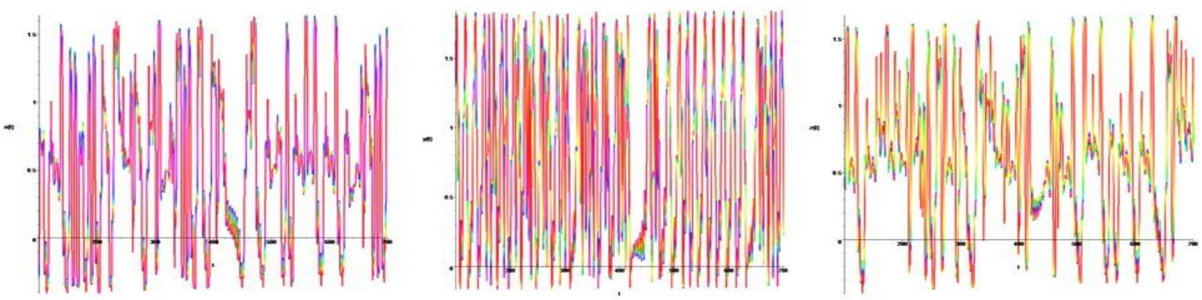

Figure 2. *Presents the temporal dynamics of x(t),y(t) & z(t) of hyperbolic Plykin - Newhouse attractor on a spherical surface if ε = 0.72.*

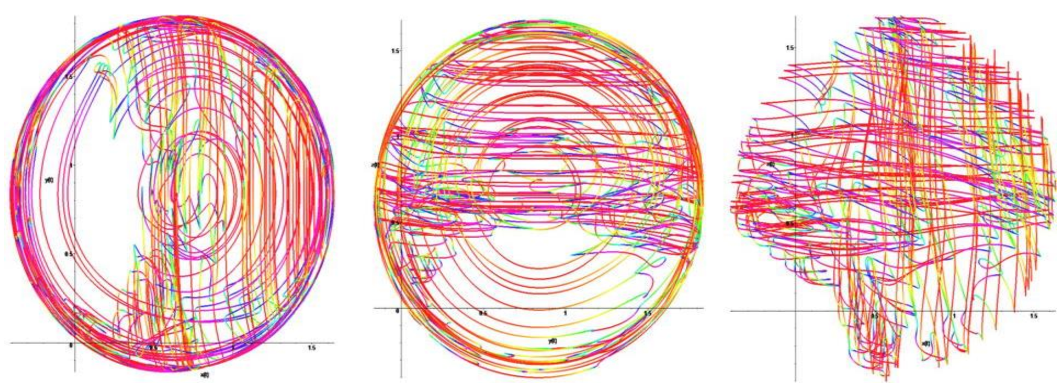

Figure 3. *Presents the temporal dynamics of x(y),z(y) & z(x) of hyperbolic Plykin - Newhouse attractor on a spherical surface if ε = 0.72.*

Figure 2 shows the temporal dynamics of y(t) of hyperbolic Plykin - Newhouse attractor on a spherical surface if $\varepsilon = 0.72$. Fig.3 left shows temporal dynamics of y(t) and the Fourier spectrum on the right presents the temporal dynamics of y(t) and wavelet transform hyperbolic Plykin - Newhouse attractor on a spherical surface if $\varepsilon = 0.72$. Hyperbolic Plykin - Newhouse attractor on a spherical surface in figure 1. and figure 3 show the bifurcation and chaotic.

3. We apply the method of Pyragas for hyperbolic Plykin - Newhouse attractor on a spherical surface

For control and synchronization of hyperbolic Plykin - Newhouse attractor on a spherical surface we apply the method of Pyragas [13] by the equation (2).

$$\begin{aligned}
\dot{x} &= \pi y\left(\tfrac{\sqrt{2}}{2} z + \tfrac{1}{2}\right) - \varepsilon x y^2, \\
\dot{y} &= -\sqrt{2}\pi z x - \tfrac{1}{2}\pi\left(x+z\right) + \varepsilon y\left(x^2+z^2\right) + 2\pi\mu\left[y(t-\tau) - y(t)\right], \\
\dot{z} &= \pi y\left(\tfrac{\sqrt{2}}{2} x + \tfrac{1}{2}\right) - \varepsilon z y^2, \\
1 &= x^2 + y^2 + z^2.
\end{aligned} \tag{2}$$

For dynamics (μ/τ) of hyperbolic Plykin - Newhouse attractor on a spherical surface we apply the method of Pyragas by figure 4.

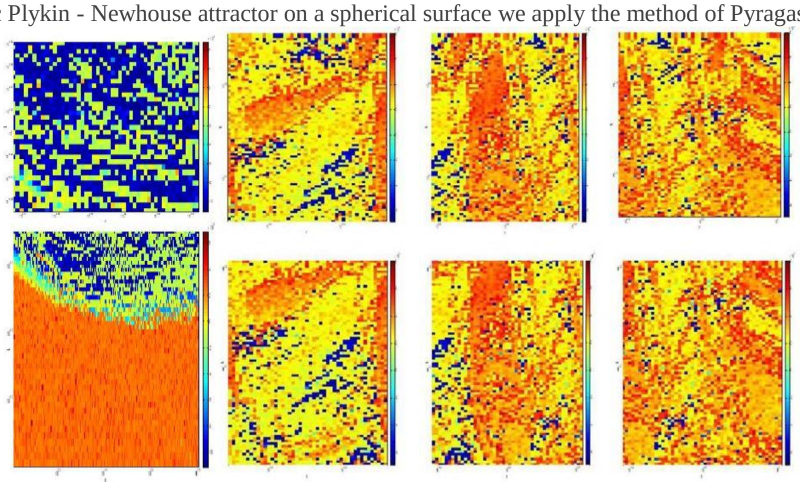

Figure 4. *The left graph shows the dynamics with negative parameters μ. The right graphs show the dynamics with positive parameters μ. Blue color is stable dynamics, yellow color is not stable dynamics, red color is chaotic dynamics.*

4. Displaying analogies between a mathematical model and waves on the surface of the brain

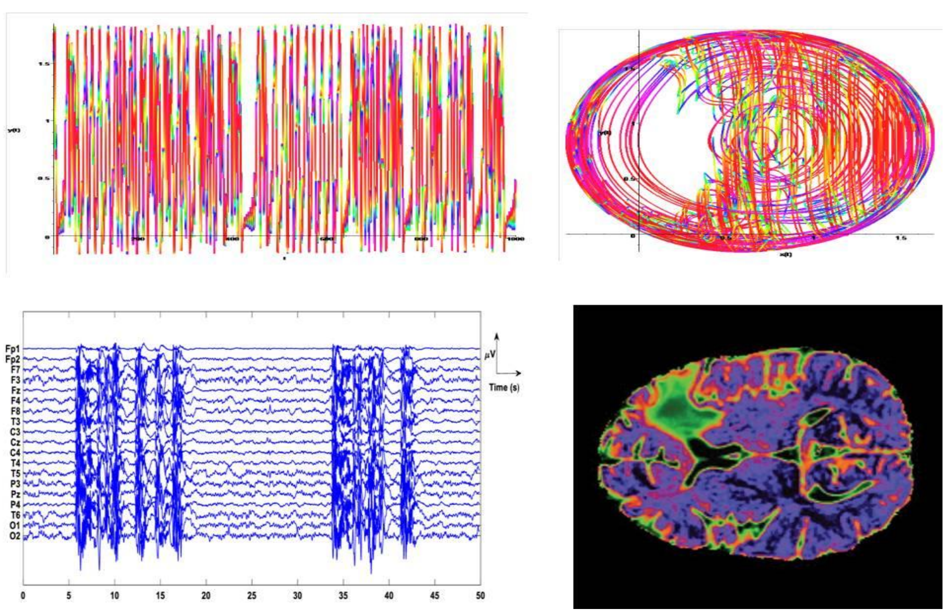

Figure 5. *Milestone charts Timeline y(t) and phase portraits y(x) of the attractor Plykin - Newhouse. Lower graphs Electroencephalogram and Brain Perfusion.*

Fig.6 shows on the left the temporal scale amplitude $y(t)$, to the right of the phase portrait of $y(x)$, in the absence of external influence on the attractor. It is easy to see that, at these parameter values the attractor has strong chaotic properties.

When using the method of Pyragas $\mu = 0.1 \rightarrow 1.0$, $\varepsilon = 0.72$, $\tau = 1.9$ is observed evolutionary dynamics of phase portraits of the system shown in Fig.6.

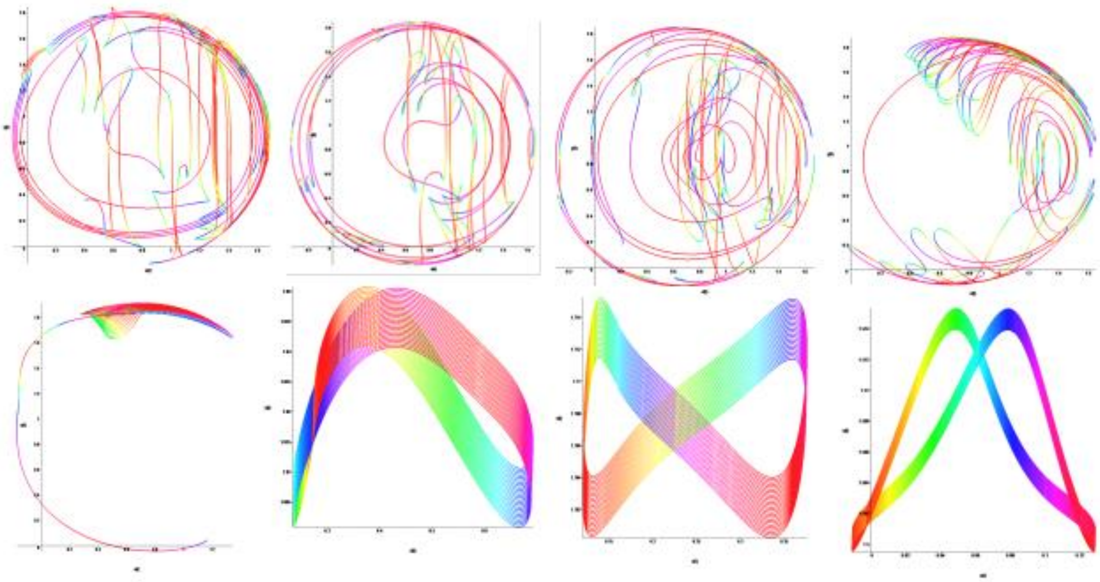

Figure 6. *Phase portraits of $y(x)$ of the Plykin - Newhouse attractor when $\mu = 0.1 \rightarrow 1.0$, $\varepsilon = 0.72$, $\tau = 1.9$.*

A positive impact on the attractor the attractor translates the pole on the positive sector of the equator. Attractor points *A*, *B*, *C* and *D* closer together forming a stable periodic attractor.

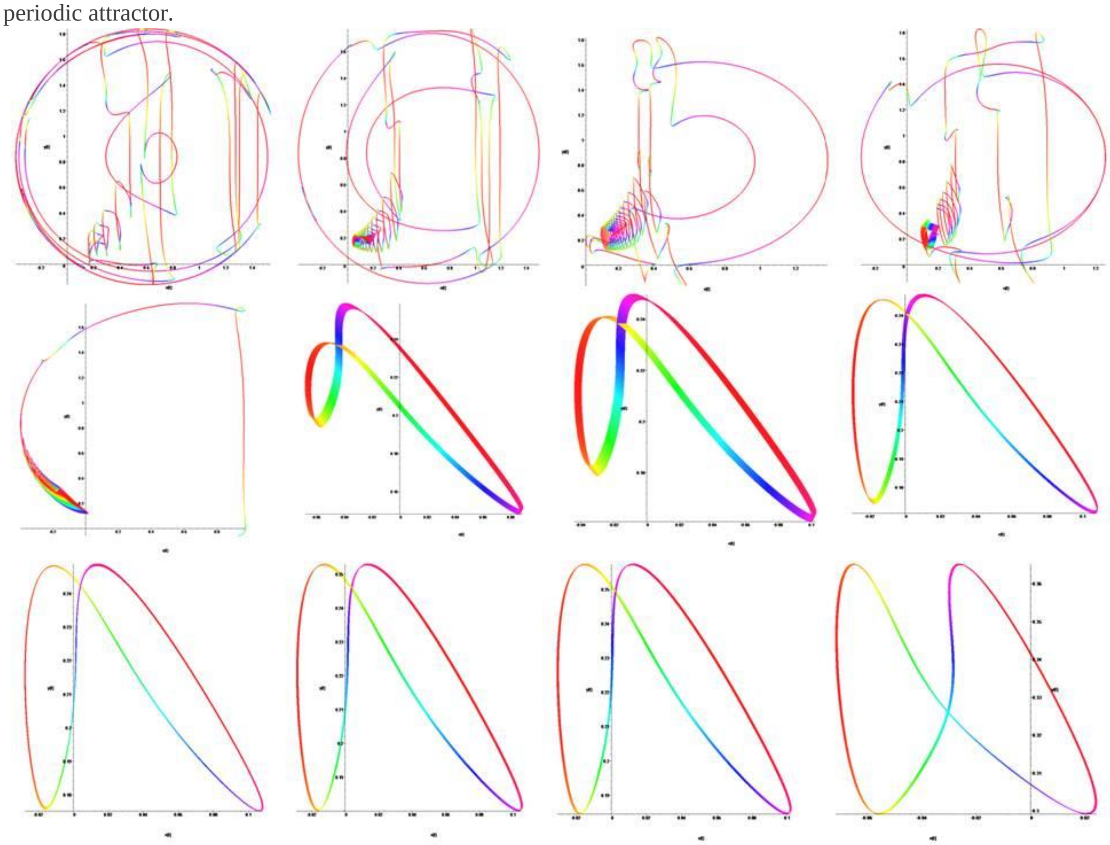

Figure 7. *Phase portraits of $y(x)$ of the Plykin − Newhouse attractor when $\mu = -0.1 \rightarrow -1.0$, $\varepsilon = 0.72$, $\tau = 1.9$.*

For transformation of flat system back to the spherical model we use the system of equations (2). Fig.7 shows on the left the temporal scale amplitude $y(t)$, to the right of the phase portrait of $y(x)$, in the absence of external influence on the attractor. It is easy to see that, at these parameter values the attractor has strong chaotic properties.

When using the method of Pyragas $\mu = -0.1 \rightarrow -1.0$, $\varepsilon = 0.72$, $\tau = 1.9$ is observed evolutionary dynamics of phase portraits of the system shown in Fig.7.

In case of positive or negative impact ($\pm K$), the change of state from not stable to stable state is made by a jump.

And the hyperbolic attractor degenerates into the limiting cycle, and the continuous spectrum corresponding to chaotic oscillations changes into an equidistant one with the frequencies corresponding to the basic frequency and its harmonics. Thus, the application of the method of Pyragas at a constant time delay, gives the opportunity to observe the evolutionary dynamics of systems of hyperbolic Plykin - Newhouse attractor [13].

5. Result

In case of positive or negative impact ($\pm \mu$), the change of state from not stable to stable state is made evolutionarily.

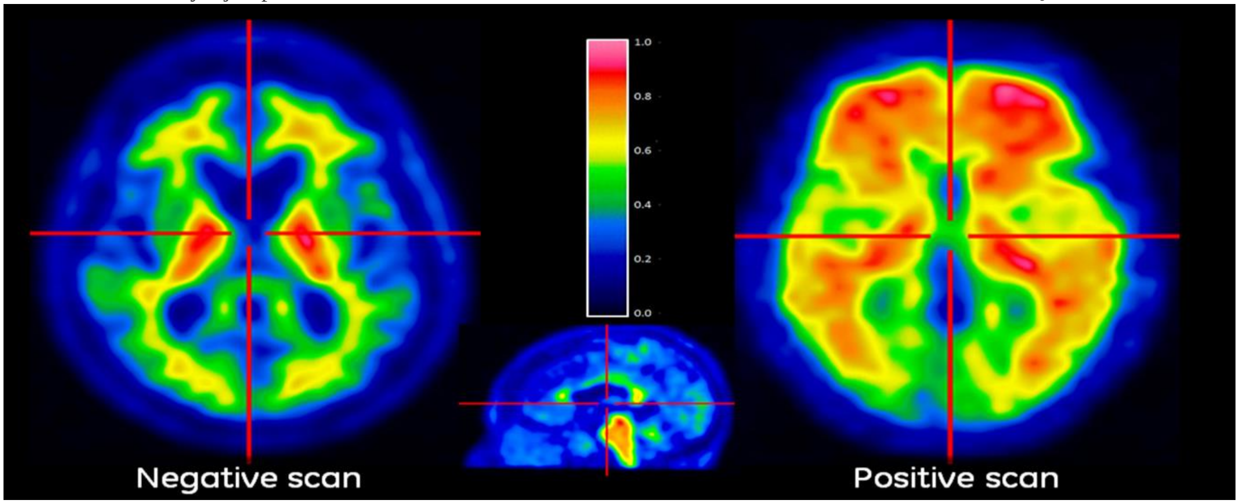

Figure 8. *Neurodegenerative and healthy state of the human brain.*

The right graph of Fig.8 of the positive scan corresponds to the first graph of Fig.3. The negative scan of the left Fig.8 where the red spots are located corresponds to the fifth graphs of Fig.(6,7).

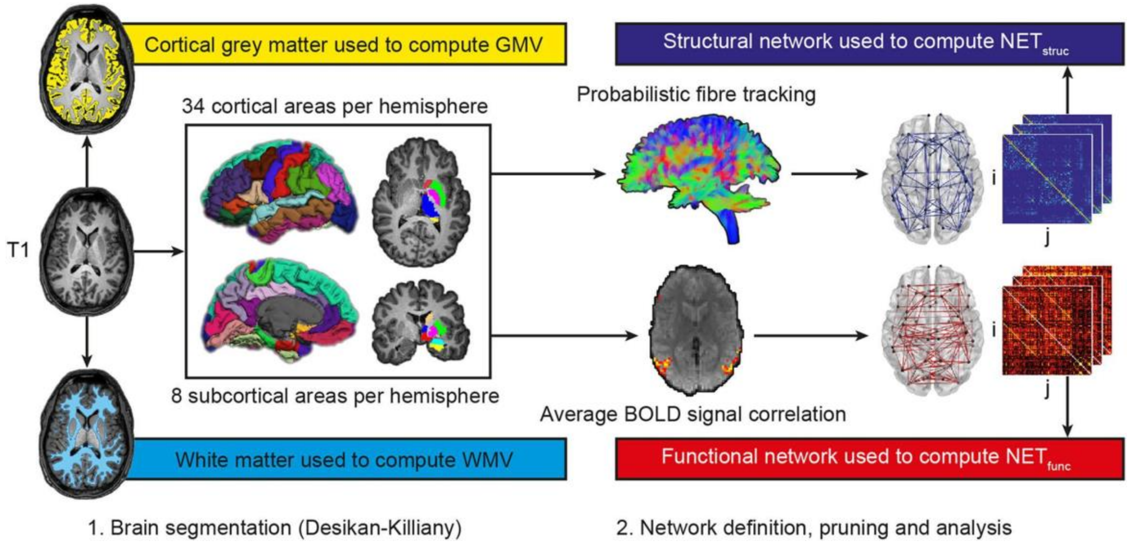

Figure 9. *3D visualization of the brain and its computer processing of data arrays of neural networks.*

Currently, it has become fashionable to identify the human brain with an array of neural network databases Fig.9 [14], although real networks look much more complicated Fig.10 [15].

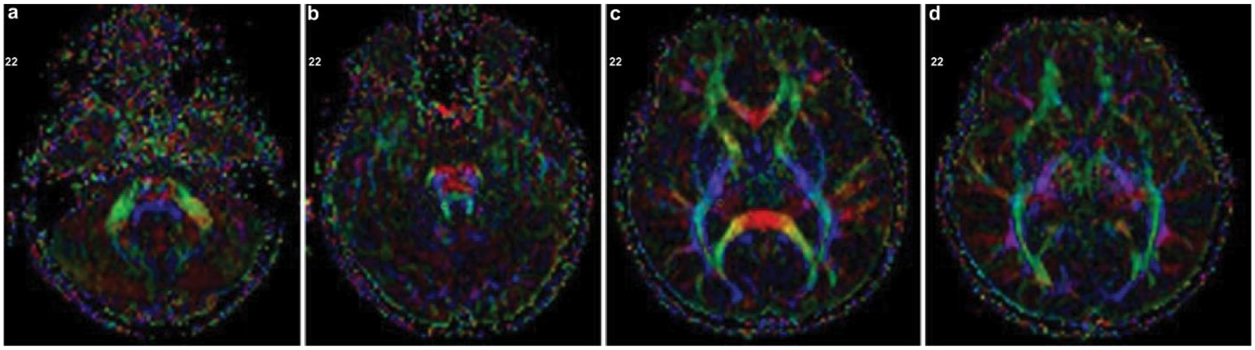

Figure 10. *A real neural network of the upper part of the brain.*

6. Conclusions

The hyperbolic attractor degenerates into a limiting cycle, and the continuous spectrum corresponding to chaotic oscillations changes to equidistant with frequencies corresponding to the fundamental frequency and its harmonics. Thus, the application of the Piragas method with a constant time delay makes it possible to observe the evolutionary dynamics of neurodegeneration using this mathematical model.

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