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Fractal Based Analysis of Movement Behavior in Animal Foraging

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Abstract: *Foraging is searching for wild food resources. Foraging theory is a branch of behavioral ecology that studies the foraging behavior of animals in response to the environment, where the animal lives. The movement of animals in searching for foods is random walk that has fractal characteristics. Fractal theory is a useful approach that widely been used in analysis of random walks. Beside several works reported in fractal analysis of movement behavior of animal foraging, no work has considered the concept of memory and fractal approach simultaneously for modelling of this behavior. In this editorial paper, we will discuss the mportance of employing fractal theory in analysis of complexity, memory content and modelling of movement behavior in animal foraging. Based on the introduced concepts, we will give several outlines for future works.*

Fractals Theory and Complexity Analysis

Fractal theory has been used widely for studying the scaling properties of different biological and ecological time series [1-3]. A phenomenon showinga repeating pattern at every scale is called fractal [4]. Fractals can be regular or complex [5]. In fact, fractal objects can be characterized using a scaling exponent that is called fractal dimension. Regular and complex fractals have integer and non-integer dimensions respectively [6]. In case of all fractals, the fractal dimension should satisfy the Szpilrajn inequality [7]:

$$\aleph \geq D_T \quad (1)$$

Where $\aleph$ and D_T are fractal dimension and topological dimension respectively. Fractal and Euclidean geometries are related to each other in building objects by applying processes to build blocks [7]. In case of a fractal time series, all fluctuations are correlated with each other based on power law. This correlation brings the concept of memory into account [8]. In application of fractal theory, we can call the works on analysis of DNA [9], eye movement [10], EEG signal [11], bone structure [12], respiration signal [13], human stride time series [14] and face [15]. In case of fractal analysis of animal movement, several works have been reported in literatures. For instance, Etzenhouser et al. [16] analyzed the movement patterns of white-tailed deer and Spanish goats in order to test the relation between foraging movements and environmental heterogeneity. They found out that the foraging paths of goats are more complex, having greater fractal dimension. In another work, Webb et al. [17] did fractal analysis to characterize movement paths of white-tailed deer. They found that females' movement path is more complex than males and concluded that females are able to forage more intensively in a smaller area. Also, look at [18-20].

Memory Concept

Memory is an important concept that is discussed in case of random walks. In employing of fractal theory for analysis of movement behavior, we can brings the Hurst exponent into analysis in order to talk about the memory content of process.

The Hurst exponent can have any value in the range of 0-1. In case of Brownian motion that does not show any persistence in the motion, Hurst exponent has the value of H = 0.5. In this case, the process is completely random without any memory. In case H < 0.5, the process is anti-persistent. On the other hand, in case of H > 0.5, the process is persistent [21-23].

Therefore it can be said in case of H = 0.5 the process does not have any memory, but in case of H = 0 or 1, the process has highest level of memory. Therefore, the closer value of Hurst exponent to 0.5, the process has less memory. For instance, a process with H = 0.3has higher memory compared to a process with H = 0.4. Similarly, a process with H = 0.9 has higher memory compared to a process with H = 0.7.

Similarly, there has been variety of works in biology and medicine that employed Hurst exponent for analysis of random walks. Using Hurst exponent in investigation about EEG signal [24] and human gait [25] are noteworthy to mention. Very limited works have been reported in literatures that consider Hurst exponent in analysis of animal movement. MacIntosh et al. [26] employed the Hurst exponent for analysis of fractal time in binary dive sequences of little penguins. The result of their analysis showed that dive sequences are long-range dependent and persistent. Also, look at [27]. However, none of the reported works discussed about the memory aspect of Hurst exponent. Bringing the concept of memory using Hurst exponent in analysis of animal movement can solve many phenomena in their behavior of searching for foods.

Modeling

An important step after analysis of random walk is working on modelling. Modelling of random walks can be done using different approaches. During years, fractal theory has shown its importance in modelling of random walks [28]. Scientists have used different types of fractal models in order to model different processes in biology and medicine. For instance, in [8] we developed a model based on Fractional Diffusion Equations (FDE) in order to model the behavior of Electroencephalogram (EEG) signal in response to external stimuli. In another work [14], similar model has been used for modelling of Human Gait time series due to auditory stimuli. In a similar approach, we can employ different types of fractal equations in order model the animal movements in searching for foods. In this model, food is considered as external stimulus that arouse the attention of animal, and accordingly animal will do the random walk to search for it. This modelling will allow us to predict the movement of animal that is our ultimate goal. This modelling has advantages over the last reported mathematical models [29-31] that did not consider the memory concept of animal movements using Hurst exponent, which relates animal movement to its fractal dynamics. In addition, other methods such as machine learning can be applied for this purpose with considering the fractal phenomenon. For instance, a fractal deep learning neural network with a varied time delay can be developed to predict the variations of animal random walk based on fractal behavior.

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