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Fractal analysis on human dynamics of library loans

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ABSTRACT

In this paper, the fractal characteristic of human behaviors is investigated from the perspective of time series constructed with the amount of library loans. The values of the Hurst exponent and length of non-periodic cycle calculated through rescaled range analysis indicate that the time series of human behaviors and their sub-series are fractal with self-similarity and long-range dependence. Then the time series are converted into complex networks by the visibility algorithm. The topological properties of the networks such as scale-free property and small-world effect imply that there is a close relationship among the numbers of repetitious behaviors performed by people during certain periods of time. Our work implies that there is intrinsic regularity in the human collective repetitious behaviors. The conclusions may be helpful to develop some new approaches to investigate the fractal feature and mechanism of human dynamics, and provide some references for the management and forecast of human collective behaviors.

1. Introduction

In recent years, the studies of statistical characteristics of human behaviors have attracted much attention from many various research fields. In the past, it was generally assumed that human behaviors happen randomly. One of the conclusions from this assumption is that such behaviors can be described with a Poisson process. Since 2005, as the inter-event time distribution, i.e. the distribution of time intervals between two consecutive events, of many behaviors in daily life and work are being investigated [1,2], people found that human behaviors exhibit an inhomogeneous feature with bursts and heavy tails, namely, the inter-event time distributions behave like a right-skewed power-law shape. From then on, close attention has been paid to human dynamics research both in the temporal scaling law [3–6] of human communication, web access, work and circadian patterns and in the spatial scaling law [7–9] of human mobility. Additionally, many dynamic mechanisms have been proposed to explain the origin of the power-law distribution [1,10–12].

Besides the temporal-spatial scaling law from the perspectives of individual, collective and group, fractal characteristic of human behaviors has also got some concern from many scholars. As early as 2000, Plerou et al. [13] found long-range dependence in stock price changes, in other words, the trading activity tends to keep the same trend as past for a considerable time. Then Paraschiv-Ionescu et al. [14] investigated the fundamental pattern in human physical activity and found the fractal structure which may be disrupted by chronic pain. Recently, Rybski et al. [15] discussed the presence of temporal

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Table 1
The amount of data points in the time series.

Time series	Month	Day	Hour	Inter-event time
A	7	180	1626	2000
B	46	1019	4000	2000

correlations in the individual activity of short-message communications, and showed that the dynamics of the more active members display clear long-term correlations. All the results imply that human behaviors exhibit fractal features. Inspired by these previous researches, fractal characteristics in human dynamics have been investigated from a distinct perspective based on library loans in our work.

Given that people always repeat some actions in certain periods, the amount of events can be seen as a time series. Time series is defined as a set of quantitative observations recorded at a specific time and arranged in chronological order [16,17], which attracts special attention due to its practical and theoretical importance in physics, biology, economics and society. Theoretical physics is one of the basic origins of the ideas and methods. Applications of physical theories have led to fruitful achievements in this field. The studies of time series are helpful to find underlying rules of observations and forecast future trends. Time series analysis may become a vigorous tool to investigate the intrinsic relationship of human behaviors among different periods and make further efforts in predicting and managing the complex social system.

Our present research is organized as follows: In Section 2, the numbers of books borrowed by library readers in a certain period are used to construct time series. In Section 3, we verify that all the eight time series and their sub-series are long-term correlated by calculating the Hurst exponent and the length of non-periodic cycle with rescaled range analysis. Then a revised linear regression method based on the cycle length is performed to forecast the future library loans. After that, the time series are converted into complex networks through the visibility algorithm in Section 4, and we find that those mapped networks exhibit scale-free and small-world properties, confirming that the original time series have fractal features. Finally, conclusions and discussions are given in Section 5.

2. Data specification

The data used in this paper were collected from two libraries of different universities with distinct professional backgrounds in China. Both datasets contain some essential information to perform the statistical analysis, including user IDs, book IDs, time at which book were checked out with second resolution. The sum of unique individuals in dataset A is 13,866, including undergraduates, postgraduates and teachers. The total transactions reach 139,606 from Sept. 1, 2008 to Mar. 30, 2009. By contrast, all the 3852 undergraduate users in dataset B come from the same grade and they created 328,795 items between Oct. 12, 2005 and Jul. 2, 2009. Our previous work [18] has verified that inter-event time distributions of book-borrowing and returning follow a power-law on both collective and individual levels, implying the heterogeneity of human behaviors.

We take the amount of library loans, i.e. how many books have been borrowed in certain period of time, as the observations of time series, using month, day and hour as units to study human behaviors. In addition, since inter-event time is a key indicator in human dynamics, two time series of inter-event time in seconds are constructed to explore the correlation between the numerical values of inter-event time.

Table 1 gives the data volumes of all the time series. Actually, there are 139,605 and 328,794 data points in the time series of inter-event time A and B, and 12,377 data points in time series B with the time unit in hours. Due to that linear increase of data volume will bring geometrical growth in computational complexity, only the front parts, 2000 or 4000, of the total data, which are enough to support our research, are considered. Meanwhile, nonworking days and hours without library loans have not been recorded, leading to the fact that the data volumes in different time units do not correspond to each other.

3. Fractal analysis of library loans time series

3.1. Hurst exponent of time series

The Hurst exponent H, namely the long-range dependence exponent is used as a measure of the long-term memory or the autocorrelation of time series, which has been extensively used in many fields such as stock markets. Theoretically, the value of the Hurst exponent is in the range from 0 to 1 with a dividing point at 0.5, which reflects the uneven level of the time series. The closer H gets to 0.5, the more noise and fluctuation there will be in the time series. In contrast, when H deviates more from 0.5, the time series will be more regular and persistent. More specifically, if $0.5 < H < 1$, the time series will exhibit persistence which means when the time series have been up or down, they are likely to continue to be up or down in the future. Conversely, if $0 < H < 0.5$, the time series perform anti-persistence.

In this section, we use rescaled range analysis [19,20] (hereinafter referred to briefly as R/S analysis) to obtain the Hurst exponent of time series shown in Table 1. For every sub-series I_a with length n, which means there are n data points in each