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Collective behaviors of book holding durations

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ABSTRACT

Duration can directly reflect the collective reading behaviors of library user book holding. In this paper, by introducing the burstiness and memory coefficients, we empirically investigate the collective book holding behavior of three university libraries. The statistical results show that there are similar properties among the students with different backgrounds, presenting the burstiness $\langle B\rangle = -0.2$ and memory $\langle M\rangle = 0.5$ for three datasets, which indicates that memory and random effects coexist in student book holding durations. In addition, we analyze the behavior patterns without duplicate durations by merging a series of books borrowed and returned at the same time. The results show the average burstiness B increases to -0.16 and memory M drops to 0.16 for three datasets, which indicates that both duplicate behavior and student's preference affect the memory effect. Furthermore, we present a model which assumes student's next book holding duration follows the previous one with probability p, and with probability $1-p$, the student would hold the book independently. The experimental results show that the presented model can reproduce the burstiness and memory effect of student book holding durations when $p = 0.5$ for empirical datasets and $p = 0.2$ for de-duplicate datasets, which indicate that the student's preferential holding behavior occurs with the probability p. This work helps in deeply understanding the regularity of duration-based human behaviors.

1. Introduction

Collective behaviors of online users have been extensively investigated, which is of great significance for identifying the behavior patterns [1–3]. Oliveira et al. [4] found the scaling-law in Darwin's and Einstein's correspondence patterns. Brockman et al. [5] argued that the distribution of human travelling distances decayed as a power law. Saramäki [6] analyzed the mobile phone call pattern and found that human had persistence communication pattern. Besides the offline behaviors, the online behaviors, such as rating behaviors [7,8], posting behaviors [9–11], and web surfing behaviors [12–15], exhibited burstiness and memory effects. To explain the behavior patterns, the task- and interest-based models have been proposed. Task-based models [16–19] believed that human behaviors could be described as a decision-based process and tasks were executed according to their priorities. Interest-driven models [10,20–22] argued that the interest played an important role in human behaviors. Besides, circadian-driven models [23,24] found that the day–night or weekly pattern existed in human behavior.

The book holding behavior may be affected by various endogenous and exogenous factors, including user's preference or interest [25], social influence [26], and the quality of book [27]. Vázquez et al. [19] investigated the inter-event time of borrowing behavior and found that it followed heavy-tailed distribution. To understand the inter-event time, the burstiness and memory coefficients were proposed [28]. Burstiness is the intermittent increases and decreases in activity or frequency of an event [1], measured by the coefficient of variation [28]. Memory is the similarity between two consecutive actions of an individual [7], calculated as a first-order autocorrelation function of time series [28]. Goh and Barabási [28] found that the inter-event time of the borrowing behavior had high-burstiness and low-memory properties. The above works mainly focus on the interval time between consecutive borrowing behaviors, which indicate the user's visiting pattern of book borrowing. However, book holding duration contains more information for understanding the user's reading behavior.

In this paper, we empirically investigate the collective behavior of the book holding durations. As illustrated in Fig. 1, the 1st, 2nd and 3rd books are borrowed at the same time but the hold-

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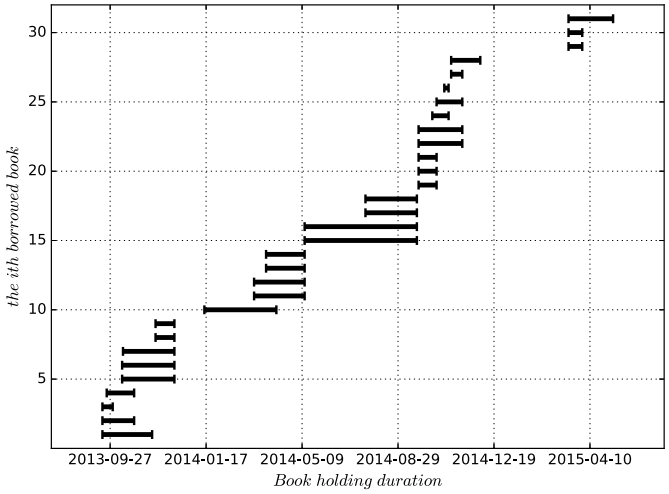

Fig. 1. The book holding durations of one student.

ing durations are different. The 10th and 11th books have similar holding durations although they are borrowed and returned in different time. And the 5th, 6th and 7th books are borrowed and returned at the same time, which are regarded as duplicate durations. The burstiness and memory effects are introduced to measure the collective properties. Then we present a model to reproduce the burstiness and memory effects of student book holding durations, and find that there are memory and random effects for the next book holding duration. Furthermore, we analyze the behavior patterns of three datasets without duplicate durations, and the results show that both duplicate behavior and student's preference affect the memory effect.

2. Empirical analysis

2.1. Data description

Three empirical datasets including the USST, SISU, and SNU are introduced in this paper which contain timestamps and student book borrowing-returning records (see Table 1 for basic statistics), where time span ranges from July 1, 2011 to June 30, 2015. The book holding duration from borrowing to returning is denoted by τ. The book holding duration sequence of student j is denoted as $\{\tau_{j1}, \tau_{j2}, \ldots, \tau_{jn_j}\}$, where n_j is the number of the borrowed books and $\tau_{j,i}$ is the holding duration of the ith book for student j. Since the collected data span four years, we use the average number of borrowed books per year $\langle n \rangle$ as average book borrowed index. In this paper, we only take students who had borrowed more than 10 books ($n_j > 10$) into consideration.

2.2. Measurements

For student j, burstiness B and memory M [28] are calculated to measure the physics of the student behaviors, in which the burstiness B_j of student j can be calculated by:

$$B_j \equiv \frac{(\sigma_{\tau_j}/m_{\tau_j} - 1)}{(\sigma_{\tau_j}/m_{\tau_j} + 1)} = \frac{\sigma_{\tau_j} - m_{\tau_j}}{\sigma_{\tau_j} + m_{\tau_j}}, \tag{1}$$

where m_{τ_j} and σ_{τ_j} are the mean and standard deviation of durations $\{\tau_{j1}, \tau_{j2}, \ldots, \tau_{jn_j}\}$. The value of burstiness B_j lies in $[-1, 1]$. The positive value of B_j means there are long/short book holding durations in regular durations and the negative value of B_j corresponds to regular durations for student j.

Table 1
Basic statistical properties of the datasets including the number of readers N_r, the number of books N_b, and the borrowing-returning records E for all students; the mode of book holding duration (unit: Day) $Mo(\tau)$, the mode of borrowed books per year $Mo(n)$ and the mode of standard deviation of book holding durations $Mo(\sigma_\tau)$ for the students who had borrowed more than 10 books.

Datasets	N_r	N_b	E	$Mo(\tau)$	$Mo(n)$	$Mo(\sigma_\tau)$
USST	29,988	222,606	651,548	31	11	25
SISU	14,392	147,164	411,831	33	11	24
SNU	52,282	365,676	955,449	29	11	16

Meanwhile, the memory M_j of student j is given as:

$$M_j \equiv \frac{1}{n_j - 1} \sum_{i=1}^{n_j - 1} \frac{(\tau_{j,i} - m_1)(\tau_{j,i+1} - m_2)}{\sigma_1 \sigma_2}, \tag{2}$$

where $\tau_{j,i}$ is the holding duration of the ith book for student j, $m_1(m_2)$ and $\sigma_1(\sigma_2)$ are the mean and standard deviation of $\tau_{j,i}$ ($\tau_{j,i+1}$), respectively. The value of memory M_j lies in $[-1, 1]$. It's noted that M_j is positive when a long/short book holding duration tends to follow a long/short one, and M_j is negative when a short/long duration is likely to be followed by a long/short one for student j.

2.3. The numerical results

Fig. 2 shows the distribution of the burstiness B and memory M, from which one can find that the average burstiness $\langle B \rangle = -0.2$ and memory $\langle M \rangle = 0.5$ are the same in student book holding durations regardless of the student backgrounds.

After calculating burstiness B and memory M of each student's book holding durations, one can obtain the distributions of burstiness B and memory M for three empirical datasets. Then a null model is introduced to compare with the empirical results, which is constructed as follows: (i) Remain the borrowing-returning relations between students and books, (ii) Randomly generate each holding duration according to uniform distribution $U(0, 60)$, where the parameter 60 is set according to library policy: it is free for student to hold books for less than 60 days. In addition, if books are borrowed and returned at the same time, we merge these duplicate durations as one record, in order to eliminate the artificial enhancement of memory effect. The de-duplicate datasets are also used to compare with empirical results.

From Fig. 2, one can find that, for the null model, the average burstiness $\langle B \rangle = -0.28$ and memory $\langle M \rangle = 0$. The different results of burstiness between empirical and null model results suggest that empirical student book holding durations have random property. In addition, empirical memory $\langle M \rangle = 0.5$ is much larger than the value $\langle M \rangle = 0$ of the null model, which reports the strong memory effect on student book holding durations. Furthermore, the de-duplicate results show that the average burstiness B increases to -0.16 and memory M drops to 0.16 for three datasets comparing to the results of empirical datasets.

3. The model analysis

3.1. The model construction

To regenerate collective behaviors of book holding durations, we present a construction model. In this model, we assume that there are two different mechanisms for holding books, namely preferential book holding behavior and random book holding behavior. When a student reads a book, he/she might borrow other reference books with high probability of similar holding duration, which is denoted as preferential book holding behavior. Alternatively, when the student is interested in a new book, the holding