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Temporal patterns of emergency calls of a metropolitan city in China

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HIGHLIGHTS

- We found that most people rarely make emergency calls while a few outliers make a lot.
- The distribution of inter-call durations decays as double power law along with an exponential tail.
- The bursty and memory behaviors of emergency calls are more prominent than normal human communication.
- We propose an event-driven memory process to model the primary pattern of emergency call behavior.

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ABSTRACT

Quantitative understanding of human communication behavior, one of the fundamental human activities, is of great value in many practical problems, ranging from urban planning to emergency management. Most of the recent studies have focused on human communication under normal situations. Here, we study the temporal patterns of emergency calls, which is a special kind of human communication activity under emergency circumstances, by analyzing a dataset of emergency call records that collected from a metropolitan city in China during a five year period. We find that most individuals rarely make emergency calls. The distribution of inter-call durations decays as double power law along with an exponential tail. We also discover that, comparing with the normal communication activities, the activity of calling the emergency number shows more significant characteristics of burstiness and memory. We further demonstrate that the behavior of calling the emergency number when people encounter extreme events could be explained by an event-driven memory process.

1. Introduction

A number of recent studies have observed remarkable statistical regularities in human communication dynamics under normal situations [1–12]. Yet our quantitative understanding of human calling activity under emergency circumstances [13–20], which indicates the requirements of accessing to police, fire and ambulance services, remain limited. Quantitative

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study of human calling dynamics under emergencies would provide helpful insights into many practical problems, such as emergency response, emergency resource allocation, urban planning and traffic management.

With the availability of empirical datasets that capture human communication activity, such as letters, emails, mobile phone calls, short-text messages and online social networks, much effort has been devoted to exploring human communication dynamics under normal conditions [1–4,6–13,21–32]. More specifically, Candia et al. found that the inter-call time distribution for calling activity of mobile phone users from a European operator, at the group level, follows a power law with an exponential cutoff [13]. Jiang et al. studied the calling activity of mobile phone users from a Chinese operator. At the population level, they also reported exponentially truncated power law distribution for the inter-call time between two consecutive outgoing calls; at the individual level, they reported various groups of calling patterns, including power law and Weibull groups [11]. By adopting the (M, B) phase diagram and the distribution of burst sizes, some studies suggested significant burstiness but weak memory characteristics for human normal communication activity [9,10,25,27,28]. Furthermore, various models have been proposed to explain the statistical characteristics of human communication activities by variations of priority queue [2,6,21] and Poisson process [3,5,33], memory effect [9,22] and adaptive interest [24,34].

In order to uncover the quantitative features of human communication behavior under extreme situations, recent studies have begun to take advantage of mobile phone data to explore human behavioral patterns during anomalous events [13–20]. Previous studies have demonstrated that emergencies could trigger a dramatic increase in communication activity of the eyewitnesses [13–15]. They found that communication spikes triggered by emergencies are spatially and temporally localized. Bagrow et al. and Gao et al. further quantified the spreading of emergency information through mobile phone networks [14,15]. Altshuler et al. proposed an approach to analyze the communication dynamics in social communities during emergencies [16]. Dobra et al. proposed a system, which uses crowd sourced data of human communication activity, to detect emergency events [20]. Using mobile phone data, there are also some studies on population movement patterns during disasters [17,18].

In this work, we conduct an empirical analysis on the temporal patterns of emergency calls, which is a special kind of human calling activity, using a dataset consisting of over 22 million anonymous emergency call records (ECRs) that collected from a Chinese metropolitan city. We observe divergent and heterogeneous characteristics for the inter-call time between two consecutive incoming calls by the same individual at both the individual and group level. We find that most individuals rarely make emergency calls. The inter-call duration distribution decays as double power law along with an exponential tail. We also find that the characteristics of burstiness and memory in ECRs are more significant than that in most of the normal communication activities. We further propose an event-driven memory process to model the calling activity of individuals under emergency circumstances.

2. Materials and methods

2.1. Dataset description

Our work was carried out on a dataset of ECRs collected from a metropolitan city in China from Jan. 1, 2008 to Dec. 3 2012. The population of the metropolitan city was over eleven million for the studied period, of which over nine million were permanent residents. The ECRs dataset contained a total of 22,358,046 incoming calls from 7,724,005 distinct phone numbers. For each incoming call, the phone number of the caller and the arrival time were recorded. All incoming phone numbers have been encrypted to protect the privacy of the callers.

2.2. Methods

2.2.1. Definitions

In this paper, we define an individual as a unique telephone number that was recorded as a caller in our ECRs dataset. For simplicity, we assume that each person made emergency calls using the same phone number during the studied period. We also assume that each incoming phone number was only used by one person.

The inter-event time, τ, is defined as the time interval between two consecutive events made by the same individual. The distribution of τ at the individual level or the aggregated level is denoted as $P(\tau)$. Note that event here can be considered as a specific action such as sending an email, sending a short-text message and making a phone call. To avoid confusion with emergency event, in our study of calling the emergency number under extreme conditions, we will use "inter-call duration" to refer to the inter-event time.

For a specific year y, $C(y)$ denotes the total number of emergency calls, $C_i(y)$ denotes the number of emergency calls made by the individual i, $N(y)$ denotes the total number of individuals who made emergency calls and $N_k(y)$ denotes the number of individuals who made k emergency calls. Intuitively, $C_i(y)$ can be taken as a measure of how frequently the individual i experiences emergencies in the year y.

2.2.2. (M, B) phase diagram

The memory coefficient, M, is derived from the autocorrelation function of the inter-event time series τ_i $(i = 1, 2, \ldots)$ of a specific individual. It is defined as: