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Research Note

Characterizing information propagation patterns in emergencies: A case study with Yiliang Earthquake

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ABSTRACT

Social media has been playing an increasingly important role in information publishing and event monitoring in emergencies like natural disasters. The propagation of different types of information on social media is critical in understanding the reaction and mobility of social media users during natural disasters. In this research, we analyzed the dynamic social networks formed by the reposting (retweeting) behaviors in Weibo.com (the major microblog service in China) during *Yiliang* Earthquake. We developed a Multinomial Naïve Bayes Classifier to categorize the microblog posts into five types based on the content, and then characterized the information propagation patterns of the five types of information at different stages after the earthquake occurred. We found that the type of information has significant influence on the propagation patterns in terms of scale and topological features. This research revealed the important role of information type in the publicity and propagation of disaster-related information, thus generated data-driven insights for timely and efficient emergency management using the publicly available social media data.

1. Introduction

The emergence of social media platforms such as Twitter and Facebook changed the way we create, distribute, and share emergency information during emergencies, like natural disasters and social movements (Palen, Vieweg, Liu, & Hughes, 2009; Shklovski, Palen, & Sutton, 2008; Yates & Paquette, 2010). Social media has been successfully used for a variety of applications for emergency management, including disaster surveillance, disaster-related information retrieval and propagation, behavioral modeling, social support, and mental health management (Chen and Sakamoto, 2014; Fung, Tse, Cheung, Miu, & Fu, 2014; Gruebner et al., 2016; Imran, Castillo, Diaz, & Vieweg, 2015; Lu & Yang, 2011; Plotnick & Hiltz,2016). Among them, users' information exchanging behavior after disaster is particularly important because it could inform the emotions, opinions, and actions of the public towards disasters, and presents the propagation of critical information. It has long been recognized that people close to the event are more interested in emergency services and evacuation procedures, while people far from the event are usually more interested in general details of the earthquake (e.g. casualties) and how they could help those affected by it (e.g. donations) (Chen, Sharman, Rao, & Upadhyaya, 2013; Yom-Tov & Diaz, 2013). A good understanding of such information exchanging behavior is the basis for the research on other applications (e.g. disaster surveillance, social support, etc.), and could further improve the effectiveness and efficiency of information publication by emergency services (Ludwig, Reuter, & Pipek, 2015; Reuter, Heger, & Pipek, 2013).

There is rich literature in examining social media users' information exchanging behavior during emergencies using social media data. A study using Twitter data during Woolwich terrorist attack revealed a number of important factors that positively influence the reposting behaviors, including emotions, time lag of reposting, and the co-occurrence of URLs and hashtags (Burnap et al., 2014). Another study analyzed the copying and pasting behaviors after *Tohuku* earthquake through examining users' reposting behaviors on Twitter, and observed the diminishing effects of retweeting behaviors after disasters (Kim, 2014). A survey based study analyzed the influence of social capital in social media users' information exchange behavior under extreme disaster conditions, and found that the structural capital increases the quantity of information, while cognitive capital and relational capital increase the quality of information (Lu & Yang, 2011). Another content analysis of Chinese Weibo data depicted users' response to different

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topics during haze disasters (Wang & Bai, 2014).

In addition to aforementioned empirical analyses of factors affecting information propagation patterns, sub-graphs and network motifs are popular tools to examine such patterns in more detail. Subgraphs of social networks contain rich data to track human interactive activities, thus offered a way to characterize the information propagation patterns with higher resolution (Zhang, Li, Xu, & Vasilakos, 2015). Three-node subgraphs are frequently examined because of their strong interpretability and generalizability of the complex structure of networks (Itzkovitz & Alon, 2005; Milo, Shen-Orr, Itzkovitz, & Kashtan, 2002). The motif of subgraphs (a subgraph that occurred significantly more often in real-world networks than in random networks) is a powerful tool to define elementary structures and identify the underlying interactive activities that generate real-world networks (Milo et al., 2002). For instance, food webs possess motifs that allow the energy to flow from the bottom to the top of food chains (Milo et al., 2002); most social networks usually have motifs that allow the information to be broadcasted from the top to the bottom in the hierarchy of the community (Kempe, Kleinberg, & Tardos, 2015; Leskovec, McGlohon, Faloutsos, Glance, & Hurst, 2007; Zhou, Bandari, Kong, Qian, & Roychowdhury, 2010); human communication networks (like instant messaging) have been found to have reciprocal motifs that enable mutual conversations (Zhang et al., 2015).

The context and content has been proved to have significant influence on whom and how fast people forward information (Sutton, Palen, & Shklovski, 2005; Wang, Tong, & Lin, 2011). To understand how the content of information influences social media users' content sharing behavior during emergencies, a number of studies classified useful disaster-related information to typical types based on its content. In addition to the manual labeling of the types by domain experts, popular supervised learning methods (e.g. Naïve Bayes Classifier, Support Vector Machine, etc.) were widely adopted to label the type of information in large-scale. The popularities of different types of information were found to be heterogeneous in different events (Vieweg, 2012). A follow-up study found that five main types of informative information could contribute to situational awareness and enhance the social resilience during emergencies (Imran et al., 2015; Oh, Kwon, & Rao, 2010). A recent study further examined the interests of users in different types of information, and demonstrated that incorporating specific users' interests could enhance the performance of predicting the scale of information propagation (Hoang & Lim, 2016).

Because of the content sharing nature of information propagation on social media, *social exchange theory* has been widely used to explain the observations. Social exchange theory suggests that relationship decisions is based on the outcomes from social behaviors (Blau, 1964). There are both intrinsic and extrinsic motivations to engage in exchange behaviors. Social media users' online social behaviors (e.g. information propagation and social networking) are typical social exchange behaviors associated with a variety of outcomes, including sense of belonging, reputation, self-esteem, feeling of obligation, altruism, reciprocity, etc. (Ngai, Tao, & Moon, 2015; Shi, Rui, & Whinston, 2014; Wang, Wang, Li, Abrahams, & Fan, 2014). In particular, Twitter is a social system with both social networking and information sharing functions. There are both broadcasting behaviors and mutual conversations among Twitter users, making it an ideal platform to study the social exchanges in social systems (Kwak, Lee, Park, & Moon, 2010; Shi et al., 2014; Wu, Hofman, Mason, & Watts, 2011).

As suggested by social exchange theory, the content of information determines social media users' motivation to exchange the information during emergencies. Exchanging certain types of information could generate rewards for both the community and individual users at certain stages. For example, sharing information about casualties and damage right after an earthquake could help the community get up-to-date information; sharing information about donations in the recovery stage could help the community encourage more donations and improve the transparency of donations, and help individuals reinforce their feeling of obligation and gain reputation. However, research on the dynamic propagation patterns of different types of information after disasters is rare. To address this challenge, this research aims to study the following research questions:

- What are the differences in the propagation scale, speed, and efficiency of different types of disaster-related information?
- What are the differences in the interaction patterns of the social media users when sharing different types of disaster-related information at different stages?

The contribution of this research is twofold. First, by applying text mining and social network analysis techniques, we uncovered the difference in the interaction patterns among five types of disaster-related information propagation networks. Second, subgraph and motif analysis revealed the evolution of communication patterns from uni-directional broadcasting shapes to bi-directional conversational shapes. This data-driven research using social media data could shed light on the in-depth understanding of the information propagation patterns, thus providing critical decision support for retrieving and publishing disaster-related information on social media during emergencies.

2. Data and methodologies

2.1. Data collection

To examine the differences in the information propagation patterns during emergencies, we collected a dataset of Yiliang earthquake[1] (a series of earthquakes occurred in Yiliang on September 7, 2012) from Sina Weibo, a Twitter equivalent in China. We used the public APIs (Application Program Interfaces) provided by Weibo for data collection. We first crawled all *original posts* (9636) containing terms "彝良" (Yiliang) and one of the following two terms "震" (earthquake) and "灾" (disaster) from September 7, 2012 to April 30, 2013. Then, we collected all *reposts* (407,584) of the original posts. Eventually, the dataset contains 417,220 microblog posts, and 315,192 unique user IDs. Among all users, around 8% were residents of directly affected towns/counties, the rest were not directed affected by the earthquake. Therefore, this research investigates the information propagation of the general public, instead of focusing on the specific group of victims. It is worth noting that, we focused on the repost relationship to present information propagations. We did not use the mentioning relationship (the use of @ symbol in text) because: (a) only less than 10% of posts contained mentioning information; (b) the mentioning relationship was almost fully covered by the repost relationship (only one mentioned user was not covered).

2.2. Content annotations and classification

Exchanging different types of information could generate different rewards for people (Constant, Kiesler, & Sproull, 1994). In the context of natural disasters, social media users could not only retrieve useful information to ease their anxiety, but also obtain social approval from posting disaster-related information (Emerson, 1976). For example, exchanging information of casualties could help users and the community to get up-to-date information right after the earthquake occurred, while this type of information would become less important during post-disaster reconstruction phase (a few weeks or months later) (Shklovski et al., 2008). On the other hand, information related to

[1] Yiliang earthquake: On September 7, 2012, a series of earthquakes occurred in Yiliang (彝良) of Yunnan province. Till September 8, 2012, the earthquake had caused a total of 183,000 people affected, including 80 deaths. 7138 houses were collapsed, and 30,600 rooms were damaged.