The Role of Social Networks in Emergency Management: A Research Agenda

Linna Li, University of California at Santa Barbara, USA

Michael F. Goodchild, University of California at Santa Barbara, USA

ABSTRACT

Lack of relevant information, particularly geospatial information, is one of the major challenges in emergency management. In the past few years, geospatial information created by volunteers and facilitated by social networks has become a promising data source in time-critical situations. This paper discusses the roles that social networks can play in the crowdsourcing of geospatial information for emergency management, data generation and dissemination through social networks, and investigates the relationships and interactions in social networks. Research issues arise in the areas of data access, data quality, information synthesis, emerging patterns of human behaviors in emergencies, analysis and visualization of nested social networks, implementation of information systems for emergency management, privacy, and equity

Keywords: *Emergency Management, Information Systems, Research Agenda, Social Networks, Volunteered Geographic Information*

INTRODUCTION

The increasing complexity of society and the intensity of the interactions between humans and their environment make us more vulnerable than ever to unexpected events. Recent disasters (e.g., Hurricane Katrina in 2005, the Wenchuan Earthquake in 2008, the Haiti and Chile Earthquakes in 2010) remind us again of the fact that we are far from being prepared for emergencies. In these disasters, the direct damage to society has been enormous in terms of death, injury, and property loss. The long-term economic impact, both domestically and internationally, is more difficult to estimate. Modern technologies, especially remote sensing and GIS, have been used to monitor the situation, to locate damaged areas, and to assess severity.

Yet despite this, the full potential of geospatial data generation and dissemination mediated by information technology has not been fully realized in crisis situations (NRC, 2007). Geospatial information provided by governments is inadequate in emergencies because of cost and long production cycles, while massive volumes of imagery from satellites and aircraft may be more timely but are limited to phenomena that can be seen from above. In the past few years, an alternative source of data has emerged, created by citizen journalists who collect, report, and

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disseminate information. Such volunteered geographic information (VGI) (Goodchild, 2007) is created by amateurs using online mapping services over the Internet, such as OpenStreetMap (OSM) or Ushahidi. VGI has been proved useful in rapidly developing emergencies such as the recent Santa Barbara fires (Goodchild & Glennon, 2010), where the need for timeliness often outweighs concerns about accuracy. During the 2010 Haitian Earthquake, a mapping community was formed immediately by people all over the world, and geospatial data about Port-au-Prince were quickly generated using OSM, and used in the rescue effort.

Social networks have proven critical in such situations, because they are able to mobilize the necessary volunteers; to provide the means to share tools; and to facilitate the loose kinds of dispersed organization that are needed to make the efforts of volunteers run smoothly. In this paper we outline some of the open questions that have arisen in this context and that together might form the basis for a research agenda aimed at improving our understanding of the role social networks can play in time-critical community mapping. The paper is based on discussions that occurred in December, 2010, at a specialist meeting organized by the Center for Spatial Studies of the University of California, Santa Barbara, on the topic of Spatio-Temporal Constraints on Social Networks. At the meeting over 40 specialists from around the world discussed the state of the art in this area, the topics that needed to be researched and appropriate priorities for each topic. Although the meeting covered much broader ground, this paper focuses on the specific domain of emergency management, and summarizes the relevant discussion. Full details of the meeting, including the position papers prepared by the participants, the presentations made during the meeting, and reports of the various discussion groups, can be found at http://www.ncgia.ucsb.edu/projects/spatio-temporal/.

The rest of this paper is organized as follows. The next section discusses pressing issues in the use of geospatial data and tools for emergency management. The following section then discusses the potential benefits of integrating studies on social networks into this context, followed by a series of research questions raised by this integration. The paper ends with some concluding remarks.

EMERGENCY MANAGEMENT

In emergencies, there is a critical time constraint on evacuating affected people, locating and delivering available resources, as well as generating relevant information and distributing it to appropriate parties in a timely manner. Relevant data are crucial to making informed decisions about where to focus attention and where to distribute limited resources; however, how to obtain reliable, accurate, and timely geospatial data is always a challenge, especially in situations where disasters develop rapidly. It is extremely difficult for government agencies to send a sufficient number of trained people to the affected area for mapping and data collection. When a disaster happens, professional emergency workers are rapidly overwhelmed and scarce emergency services may be quickly depleted. In the report to the US Congress on Hurricane Katrina, Secretary of Homeland Security Michael Chertoff emphasized "the importance of having accurate, timely and reliable information about true conditions on the ground" and pointed out that the response efforts during Katrina "were significantly hampered by a lack of information from the ground" (Chertoff, 2005).

Another primary challenge in handling emergencies is information sharing and communication in order to facilitate coordination. Information needs to be appropriately shared and promptly exchanged between involved parties at the appropriate place and time. Professional emergency workers may have a special emergency management system to communicate with each other and between departments at federal, regional, and local levels. Effective communication is also vital between emergency managers and local residents for execution of evacuation plans, and between residents to help

each other to avoid risks in a self-organized manner. In addition, information updates are also important for local residents for emotional reasons. Lack of up-to-date information about the disaster and the status of family, pets, and friends may aggravate negative emotions such as fear, stress, and anxiety, which may lead to mass panic. However, existing communication channels established by various levels of government are neither sufficient nor adequately utilized to respond to major disasters. For example, the lack of an adequate and effective communication system to inform and guide the public was identified as one of the failures in the response and recovery efforts during Hurricane Katrina (White House, 2006); and in the Santa Barbara fires of 2007–2009 the capacity of the official Web sites was often insufficient to meet the demand.

BENEFITS OF USING SOCIAL NETWORKS

As discussed above, there are limited resources from government agencies to gather geospatial information rapidly, and effective communication mechanisms are lacking for information sharing and collaboration between professional emergency managers and citizens during emergencies. Social networks can play two major roles in effective emergency management. First, information generated and disseminated over social networks is incredibly valuable for disaster response. Second, the study of the relationships, behaviors, and interactions in social networks may provide important insights for gathering information, planning evacuations and sheltering, and other rescue efforts.

On the one hand, during emergencies, official sources for covering a localized disaster may be insufficient or inaccurate due to the lack of capability and resources or due to more severe disasters taking place in other places that require more attention. On the other hand, human sensors that can observe and monitor the disaster process are often densely distributed and information generated by them can be rapidly shared. The time to acquire the official geospatial information regarding a disaster can be long, while the information generated and distributed by users of online social networks can be instantaneous. In some other situations where information is strictly censored by government, social networks enable people to obtain relevant information, challenge conventional official information sources, and circumvent news blackouts. During the SARS outbreak in China in 2003, for example, text-message usage in Guangdong province had tripled between February 8th and 10th compared to the same period in the previous year, indicating high levels of social networking activity. These citizens knew this information before the Chinese government reported it to the World Health Organization on February 11th and they shared the locations of outbreaks, symptoms, and possible remedies (Gordon, 2007).

VGI is one particular type of information with a location component which is generated by social networks and is vital for emergency management. This alternative source of geospatial information over the Internet often has comparable accuracy to authoritative sources and appears to be superior to official sources in terms of currency. The importance of locations in emergencies can never be over-emphasized. Timely identification of affected people may make a difference between life and death, and timely allocation of resources to locations of greatest need is crucial for disaster relief. Several examples have shown the importance of VGI in disaster response. During the 2010 Haitian Earthquake, a group of OSM users from all over the world rapidly produced a detailed street map of Port-au-Prince which was used by crisis responders on the ground in Haiti, based on digitization of satellite imagery facilitated by social networks such as Crisis Mappers Net. The Humanitarian OpenStreetMap Team (H.O.T), through the CrisisCamp events of volunteers linked through the Crisis Mappers network, formed an open community to connect everyone involved and to integrate the work of thousands of networked volunteers world-wide in the production and maintenance of a digital

map of Haiti. After an original call to action for Haiti at 7:08pm EST on January 12, the CrisisMappers Google Group had 706 members and a history of 2364 messages, and over 574 individuals were sharing profiles through Crisis Mappers Net as of March 1, 2010 (Meier & Ziemke, 2010). Before the earthquake, the OSM map of Port-au-Prince had very limited coverage (Figure 1), but within only 48 hours, the dataset became possibly the most complete and accurate data source for that area (Figure 2). In the 2009 Jesusita Fire in Santa Barbara, several individuals established a website, with the Google Map API, to collect relevant information from both official sources and data contributed by local residents using online social network sites such as Twitter, Flickr, and blogs. In these cases, VGI is particularly crucial for disaster response in areas with insufficient data, such as Haiti. Furthermore, maps of potential risks and social vulnerability (Cutter, 2003) may be generated to describe the various probabilities of hazards in different locations and the ability of different individuals and groups to cope with disasters, which can guide disaster mitigation and preparedness.

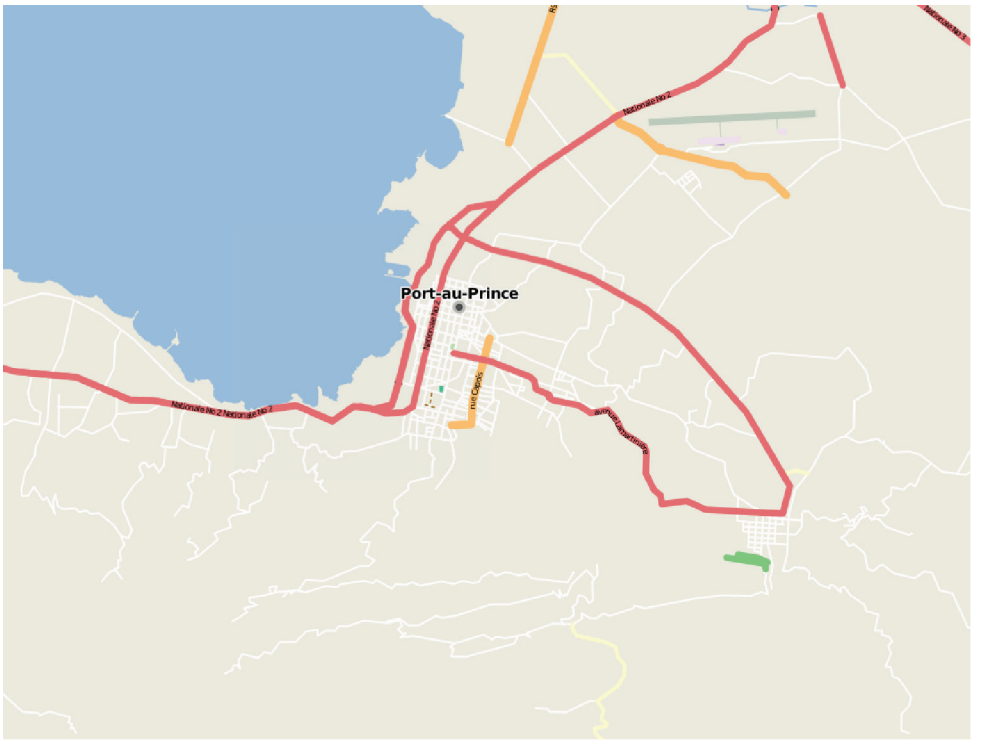
In addition to data generated from social networks, studies of relationships, interactions, and patterns in social networks are also useful in all stages of disasters. Identification of abnormal patterns in social networks within a spatio-temporal context may automatically discover locations that need more attention. For example, geo-tagged tweets were used to detect unusual social events in Japan (e.g., local festivals) by comparing tweet patterns to the usual behavior patterns of twitter users (Lee & Sumiya, 2010). Similarly, analysis of social networks may recognize the outbreak of a disease before it is noticed and confirmed by official sources. Furthermore, analysis of leaders and groups in a disaster-response effort is critical for performing tasks better.

There are three major types of social groups in emergency response. First, affected communities may be immediately involved in activities (e.g., engaging in conversations using social networking services) to report relevant information motivated by self-interest. They report what they see, take pictures and videos, and transmit rapidly to others information about what is happening at their locations. Some individuals may also establish local community sites to gather information for a particular disaster from various sources, including both official and volunteered information. Second, professional emergency workers equipped with capabilities to perform large-scale rescue efforts are assigned to disaster relief after it is reported to the government. These trained professionals are capable of coping with different disaster scenarios and have access to essential emergency assets and services; however, they may be very unfamiliar with the local situation. Third, a large number of highly motivated volunteers contribute for humanitarian reasons. They are not directly related to affected people as relatives or friends and they may not be close to the affected community geographically, but they have access to necessary computational resources to generate appropriate geospatial data. As one major contributor in the Haitian earthquake mapping effort from the Netherlands said: "Given any disaster, together with good satellite imagery, I would go at it again in a heartbeat, no matter where a disaster would take place!" In disasters, these three groups of people work together towards a common goal to reduce the impacts of disasters; however, this may be the first time that they collaborate with each other, and coordination is required when a large number of people are involved in an activity. Social network analysis may offer useful insights into this problem.

CHALLENGES IN USING SOCIAL NETWORKS

Although social networks have a great potential to benefit the acquisition and use of geospatial data and tools in emergency management, this application also raises a number of research questions across a wide range of disciplines, including emergency management, geography,

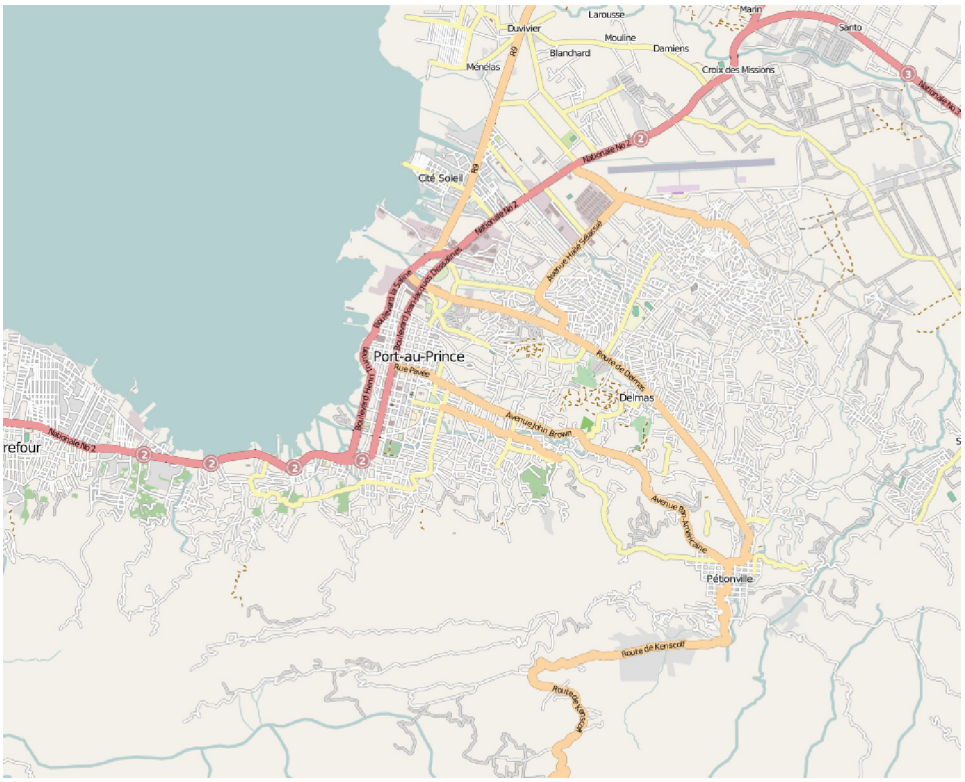
Figure 1. A comparison of OpenStreetMap coverage before and after the Haitian Earthquake (http://www.flickr.com/photos/mikel_maron/4274264767/): Before the 2010 Earthquake



sociology, computer science, geographic information science, and ethics.

First, data access and data quality are two important issues to consider before information generated in social networks can benefit emergency management. Is there an automatic way to discover relevant information for a particular disaster over the Web when a range of tools and websites are used by different groups of people? In addition, there is always a trust issue in accepting information generated by volunteers. An individual may be faced with a choice between available but potentially unreliable information synthesized by volunteers, and authoritative yet possibly unavailable information from government agencies (Goodchild & Glennon, 2010). Should he or she wait for the official information from government which may be slower, or should he or she trust VGI that is asserted without validation? Although an average citizen may choose the risk of false positives over the risk of false negatives because the consequences of the latter are more devastating, the answers to the following questions may help them make better decisions. How can we validate the information generated by volunteers on the Web? How can we quantify the uncertainty in a piece of information? Are there any metrics to evaluate the data quality of a particular contributor, e.g., from knowledge of his or her personal background, or from an evaluation of data previously generated by the same person? Is it possible to produce automatically a probability distribution of data values from multiple sources? A more perplexing situation would be a conflict between information sources, especially a contradiction between an official source and a volunteer. As discussed above, information from official sources may be validated when it is received but the delay

Figure 2. A comparison of OpenStreetMap coverage before and after the Haitian Earthquake (http://www.flickr.com/photos/mikel_maron/4274264767/): January 14, 2010



may make it obsolete when a citizen reads it. It is also useful to compare the value and appropriateness of various data types among maps, text, images, and videos through different Web services including OSM, Twitter, Flickr, Youtube, etc. Is data quality related to data format or medium? For example, are pictures and videos more objective and accurate than text messages?

Faced with information from various sources with different levels of uncertainty, another crucial question is how to synthesize geospatial information effectively from sensors (e.g., remote sensing imagery) and human observations (e.g., text, pictures, and videos), ideally in real time. Provenance and uncertainty of different sources should be maintained in synthesis, which is still a challenging issue in the database and GIScience communities. How to conflate geospatial data with various accuracies, different levels of detail, and in different formats is still an open question. Semantic interoperability is also critical in integration of data from different social groups who use different concepts to think and different languages to communicate. In addition, what data type would be the most appropriate form for integration and synthesis of various sources to facilitate reasoning and decision making? For instance, should all information be linked by geographic locations and conflated into a base map to provide a holistic view of relevant knowledge? What type of information is needed in different stages of disaster management? What type of information is needed to support evacuation by different modes, from private vehicles to pedestrians?

Besides the use of alternative data sources, it is also very important to understand the emerging pattern of volunteers who join social networks to generate and share geospatial data during emergencies. A more general research issue concerns how a social network forms, is maintained, and evolves as an emergency develops. Can social network theories in sociology be used to explain human behaviors in emergencies? How does the number of volunteers increase as the disaster develops? What factors determine the geographic distribution of information generators dynamically? What are the socioeconomic characteristics of habitual volunteers in generating and disseminating information in emergencies? When a number of highly motivated volunteers are available to generate useful information in response to a disaster, is there an effective way to assign tasks and to organize the community? Are they currently self-organized during crisis mapping efforts? Should the mapping tasks be systematically partitioned? For example, to produce geospatial information for an area, should we partition the task horizontally, which means one volunteer is assigned to work on a subarea, or should we partition the task hierarchically, which means one volunteer is assigned to work on a particular theme of the whole area? Is there a mechanism to prioritize data production in terms of areas and themes? Is there a relationship between the type of contributed information and the distance from the volunteer to the contributed area? For instance, it may be easier for a distant volunteer to generate geometries of streets using remote sensing images as opposed to street names. How can we use this relationship to assign tasks according to the distance between a volunteer and a target area? In addition, how can we identify qualified individuals with required expertise and skills and encourage them to contribute to information generation? For example, how can we identify trained GIS professionals (e.g., GIS practitioners, teachers, or students) and people with local knowledge (e.g., geographers or social scientists) when geospatial information is needed or the cultural background of affected people is crucial for evacuation? Studying behavior patterns of volunteers, such as contributors of VGI, may offer insights in these areas.

Another research issue directly related to emergency data and volunteer behaviors discussed above is social network support to facilitate information generation and dissemination, particularly VGI. Social networks allow people to access hundreds of friends, to get acquainted with like-minded people, and to coordinate millions of hours of human work. How can we utilize existing social networks to grow the VGI contributor community? How can we promote participation through socio-psychological incentives? Some social networks are not originally designed for collaborative mapping in time-critical situations. In emergencies, how can we harness different social networks to build a crowd dedicated to crisis mapping? When multiple social networks are involved, how should we define clear roles for volunteers, in order to eliminate overlap in work and facilitate coordination? Besides, social networks can be very useful for monitoring VGI quality. Similar to the self-reporting system on many user-generated-content websites, users can flag a piece of VGI as accurate or inaccurate. Social networks may also build up a moderation system where people gradually gain reputation by overall veracity and reliability. How should we give people privileges as moderators and editors in quality control? People tend to trust people in their social networks. How can we establish trust networks within existing social networks in emergencies by integrating various social networks through common nodes? As discussed above, there are three major social groups in disaster response. How can we achieve effective networking among affected communities, the emergency management agencies, and VGI contributor communities? To what extent do people involved in traditional mapping constitute a social network, and what can be learned from its structure and operation? How can the dynamic embedded networks of volunteers be represented, and what new metrics are needed to monitor them? How can we maintain a social network of volunteers propelled by a

previous disaster response effort and adapt it to another VGI project? For example, mapping communities have been formed after the Haitian Earthquake. How can we utilize social networks to motivate people to continue contributing to collaborative mapping in their leisure time, even when there is no major disaster? In this way, many of the tasks performed by OSM volunteers in the aftermath of the Haiti earthquake may be moved from emergency response to the earlier phases of risk assessment, mitigation, and preparedness. When a disaster happens, only some modifications of existing data are needed to reflect the landscape change caused by the disaster.

Social networks are embedded in geographic space and time and nested with other networks, such as transportation networks and information networks. Correlation may exist between movements in one network and activities in another network. For example, movements of cars between two locations on the road network may reflect a connection of people at the same two locations in a social network. We need to keep in mind that people rarely act independently in emergencies, but rather evacuate within groups. Parents may go to school to pick up their children before leaving town. Therefore, understanding social networks is critical for developing an optimal rescue plan such as an evacuation route. Another example is that the activities in online social networks (e.g., comments on an event) may reflect activities in the physical world (an event that people are currently experiencing, such as a football game or a fire). The study of the interactions is made possible with the development of location-based services and the large volumes of geospatial data generated by them. However, novel methods and new techniques need to be developed to capture the correlation between networks, to represent and analyze spatio-temporal dynamics of social networks, and to help emergency managers make decisions at different scales. When different social networks are combined to perform a task towards a common goal (e.g., emergency response), how can information technology be used to reorganize social networks based on geographic proximity, expertise, skills, etc., to perform tasks better? How can we facilitate interaction and collaboration among major social groups involved in emergencies using information systems?

Social network analysis is promising for understanding the current situations of people involved in emergencies, but we do not have adequate methods to conduct analysis. First, it is helpful to distinguish between real social networks and implied social networks. Real social networks are the complex relationships of people at various levels, and implied social networks are inferred from human activities. Any data we collect using either online social-network services or cell phone records are only an approximation of real social networks with simplification or even misrepresentation. Therefore, it would be useful to investigate the uncertainty of collected social-network data. What is the percentage of relationships that are represented in a particular social-network data source? How can we collect social-network data about affected people from available sources? How can we identify useful social networks from masses of disparate data? Furthermore, how can we combine data from different social-networking services, e.g., Twitter, Facebook, or phone records? Besides, representation of complex multi-level social networks is also a big challenge. Is there an effective way to generalize large complex social networks? How can cartography and geovisual analytics contribute to representations of social networks? When large volumes of data are available, what would be an effective mechanism to use to sample? How should we identify different roles of people in social networks, e.g., leaders and followers? How do we identify emerging and abnormal patterns in spatio-temporal social networks? What models can be developed to simulate social networks embedded in spatially and temporally bounded environments, and to evaluate the impacts of possible decisions? How to measure and improve the efficiency of a social-network process for effective organization and spreading of information? How to enable a social network spatially, temporally, and culturally to acceler-

ate rates of information diffusion? Is it possible to develop a theory for multi-level networks? How can we integrate existing social-network graphs with location-based services to analyze the geographic distribution of participants of a social network at a particular time-space point in order to make an optimal evacuation route taking into account social factors? When we want to send a message to a particular person who is in danger, is there a way to identify connections from this person to notify him or her?

In addition to conceptual understanding of social networks and use of valuable data, another big challenge is implementation of information systems to facilitate emergency response and to improve decision-making. During emergencies, it is very important to have effective communication between emergency managers and affected people. While social-networking tools have been used by local residents to share relevant information (Goodchild & Glennon, 2010; Longueville *et al*., 2009; Vieweg, 2010), not much research has been done to investigate the effectiveness of using social-networking tools to disseminate information or to coordinate tasks by emergency managers during the response and recovery phases. Studies are needed on information diffusion over social networks and on the effectiveness of possible channels for distributing relevant information in emergencies so that emergency managers can wisely choose platforms for giving evacuation orders. If we want to build an information system to perform tasks better in emergencies, what are the key features of this system? Can we use or adapt existing social-network services to collect and disseminate relevant information? Are currently available social-networking tools (e.g., Twitter, Flickr, Facebook) an effective service for disaster response? What kind of social-networking tools can be used to facilitate coordination between volunteers, and what features need to be added to enhance collaboration during emergencies? Is it possible to incorporate online social-networking tools into current emergency-management systems? What are the computational barriers? In addition, how can these tools be improved to address the needs of special groups including disabled individuals and people with language barriers?

Finally, there are two ethical issues: privacy and equity. When locations of residents are revealed to the public during emergencies, this information may invite future crimes, especially for disadvantaged people. Is there a way to get the required help for people and protect their privacy at the same time? Another issue concerns the various degrees of information accessibility between different groups of people. How can we reach people without access to mobile phones, computers, and the Internet? How can we disseminate relevant information to people who don't use online social-networking services? Online social networks are only a small portion of the representation of real social networks. How can we collect data on social networks that are not represented in the digital world? What would be the requirements for disseminating information to different user types, such as disabled groups and people speaking different languages or from different cultures?

CONCLUSION

Information technologies are evolving at a rapid speed and enabling people to take advantage of new opportunities and capabilities, and through them to create new information and valuable knowledge in an easily shareable format. Volunteer-created data in social networks are becoming increasingly influential, such as the geospatial data created by the OSM community. An intelligent socio-computational system for emergency management requires synthesis of data from various sources; collaboration among local residents, government agencies and volunteers; and a deep understanding of the social networks embedded in a spatio-temporal context. Methodological investigation and empirical studies in these areas may provide the foundation for establishing theories of multi-level social networks at different scales in emergency response. It is our hope that interdisciplinary research and development in social networks and emergency management

will shed light on the appropriate technologies, infrastructures, and policies and in turn increase the community's resilience and effective response to disasters.

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Michael F. Goodchild is Professor of Geography at the University of California, Santa Barbara, and Director of UCSB's Center for Spatial Studies. He received his B.A. degree from Cambridge University in Physics in 1965 and his Ph.D. in geography from McMaster University in 1969, and has received four honorary doctorates. He was elected member of the National Academy of Sciences and Foreign Member of the Royal Society of Canada (2002), member of the American Academy of Arts and Sciences (2006), and Foreign Member of the Royal Society and Corresponding Fellow of the British Academy (2010); and in 2007 he received the Prix Vautrin Lud. He was editor of Geographical Analysis between 1987 and 1990 and editor of the Methods, Models, and Geographic Information Sciences section of the Annals of the Association of American Geographers from 2000 to 2006. He serves on the editorial boards of ten other journals and book series, and has published more than 15 books and 400 articles. He was Chair of the National Research

Council's Mapping Science Committee from 1997 to 1999, and currently chairs the Advisory Committee on Social, Behavioral, and Economic Sciences of the National Science Foundation. His current research interests center on geographic information science, spatial analysis, and uncertainty in geographic data.

Linna Li is a postdoc at the Center for Spatial Studies at the University of California, Santa Barbara, interested in geographic information science theories and applications. Li received a B.S. in Earth and Space Sciences from Peking University in China in 2004, an M.S. in Geography from the University of South Carolina in 2006, and a Ph.D. in Geography from the University of California, Santa Barbara in 2010. She has a wide range of research interests, from geographical knowledge representation and communication to geovisualization, spatial analysis and modeling. Currently she is working on two projects: conflation of heterogeneous geospatial data from different sources and volunteered geographic information (VGI).