Crisis Mapping:

Big Data from a Dynamic Network Analytic Perspective

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Abstract

Big data holds the promise of enabling analysts to predict, mitigate and respond rapidly to natural disasters and human crises. Rapid response is critical for saving lives and mitigating damage. Rapid response requires understanding the socio-cultural terrain; i.e., understanding who needs what or can provide what, where, how, why and wehn. Today, new technolgies are forging a path making use of sensor and social media data to understand the socio-cultural terrain and provide faster response during crises. A review of this area, the state of the art, and known challenges are discussed. The basic argument is that this technology is still in its infancy. Critical scientific challenges, social challenges, and legal challenges will need to be addressed before the promise of big data for Crisis Mapping is fulfilled.

Crisis Mapping:

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Today we are facing unprecedented levels of change due to global climate change, population growth, economic globalization, social media penetration and ubiquitous computing. These factors when coupled with changing levels of economic prosperity, de-forestation, education, and immigration fuel the fires of change at the social and cultural level. The result appears to be waves of civil unrest and an increase in the number and scope of natural disasters. Whether due to natural events such as tsunamis, or human created conflict such as insurgencies, crisis are common in the modern world.

At the same time, an unprecedented volume of data is now available through automated sensing, social media, automated archives, and other activities that are converting what is known or even suspected into digital formats. Social media users and the amount of data they generate is increasing exponentially. New forms of data sharing such as u-tube and instagram are leading the way to an explosion of non-text data. More data providers and more means by which data can be provided are leasing to a super-exponential explosion of data.

This conjunction of these factors, crises and data, creates new opportunities and challenges for assessing and providing support for social change in the face of crises, for providing ***Crisis Maps***. The need and promise are strong. Many futurists describe in glowing terms what will be possible. Today, however, the technologies and policies needed to make such a future possible are in their infancy, particularly with respect to disaster response (e.g., Landwehr & Carley, forthcoming).

The provision of information gleaned from ”big data” to monitor potential crisis sutations, and possibly provide support is often referred to as Crisis Mapping. Crisis Maps are often created using some combination of mashups in conjunction with crowd sourced information, social media monitors, and models of the human socio-cultural environment and how it might change under

various events. Examples include: the original Ushahidi[1] system (Okolloh, 2009) used for election fraud monitoring in Kenya; the Google Crisis Map[2] (Schroeder, 2012) for real time monitoring and specific incident maps used for several recent events including superstorm Sandy with user data culled from the web; the ASU-TweetTracker (Kumer et al., 2011) to CMU/Netanomics-ORA[3] (Carley et al., 2013) system used to monitor the Benghazi consulate attacks, hurricane Sandy and Kenya elections; and Mitre's Social Radar (Costa, 2012; Mathieu et al, 2012) used to monitor Kenya elections. In these tools, data from social media and sometimes physical sensors is tracked, analyzed, visualized and used to identiy who needs what where, what is going on where, and to assess the space of possibilities for intervening and mitigating the scope of the crisis or even averting a larger disaster. Many other tools are under-development with many large corpoations, small companies, and universities involved in the development.

Crisis Maps and crisis mapping technologies are used by groups and organizations that respond to crises. These crisis responders include military organizations, such as the Navy providing hospital ships, governmental groups providing aid and services, first responers such as the police and firemen, non-governmental organizations providing support such as Humanity Roads, local church groups, aid organizations such as doctors-without-borders, and so on. Though operating in a situation where mistakes can cost lifes and harm general welfare, these are not high reliability organizations (Perrow, 1984; Schulman, 1993)– i.e., they are not operating in unforgiving social and political environments, their technologies are not necessarily risky, and they can learn through experimentation. Like high-reliability organizations, e.g. nuclear power plants, these crisis response organizations use use complex processes to manage complex work, generally in a distributed response environment where misperceptions, misinformation, and misunderstandings are rampant.

[1] http://www.ushahidi.com/products/swiftriver-platform
[2] http://google.org/crisismap/
[3] http://www.casos.cs.cmu.edu/projects/ora/

This paper provides a synopsis of the state of Crisis Mapping – what it is and how it is used – and an evaluation of the key challenges with respect to big data. The conclusions are informed by participation of the author in 8 national/international experiments using social media in the crisis response area in the past several years. Participant observation techniques, and discussions with tool providers, coupled with attendance at 6 major conferences and membership on the recent NRC committee on big data discussing Crisis Mapping during the same timeframe provided additional information.

Crisis Mapping – The Promise and Use of Big Data

Big data has the potential to revolutionize disaster response and crisis mitigation. The potential to combine social media data for local coordination and assessment with sensor data for noting changes in the geo-physical environment would enable alerts of impending natural disasters to be signalled far enough ahead to save lives and reduce damage, have an ear on the ground to identify pockets of need, social response, and social early warnings, and so on. Social media, e.g., provides local information which can serve as an early alert system, leading traditional news sources (Pfeffer & Carley, 2012b).

Today, telecommunication technology and social media are often used during crises by those in need to seek information enabling them to understand what is happening, to provide information, and to acquire aid (Shklovski et al. 2008; Arcenaux & Weiss, 2010). Increasingly, community provided information are playing a crucial role in disaster preparation, in providing warning, in crisis response and during recovery (Palen and Liu, 2007). These media are being used, in effect, to understand the socio-cultural terrain. The socio-cultural terrain can be characterized as identifying the critical who, what, where, how, why and when and connections among them. An example is identifying who needs what where after a disaster, or which crisis response groups are working with

which others and where is their region of operation. Understanding and characterizing the socio-cultural terrain is critical for designing an effective disaster response, for enabling crisis responders and local communities to self-organize to respond to disasters, and for enabling improved planning for mitigating future disasters.

The 2012 Superstorm Sandy provides an example of how telecommunication technology and social media are used in crisis response. This crisis marked a shift in the use of social media for crisis response as government agencies and first responders used social media and crisis maps to communicate with each other and the public, to gather and share information, and create and maintain awareness (Cohen, 2013). After the storm, blogs and news media published stories about the extent to which Twitter had been used (Laird 2012; Munro & Manning 2012). Blogs provide just-in-time training by publishing ”how to” information for these technologies, the use of which improves community resiliency by helping individuals help themselves. For example, prior to Sandy, blogs published guides on how to search Twitter for data (Sullivan, 2012). Our own research shows high levels of Twitter usage during disaster; but, much of it does not support disaster response such as the wealth of misinformation, exclamations over the extent of the storm, and a vast sharing of image some of which are photoshopped fpr humor. From a first responder perspective, much of the information in Twitter is simply not useful. Moreover the tweets showed a ”Bieber” effect; i.e., you could tell when the storm was over and had lost the interest of most tweeters as tweets about Justin Bieber re-rose into the top re-tweet list.

Sandy was not an anomaly from a big data perspective. Sinnappan et al. (2010) examined 1684 tweets associated with Australia’s fire disaster, referred to as Black Friday. They found that only 5% contained directly actionable information. Nor is the plethora of less than useful information limited to Twitter – e.g., on Sina Weibo, the ”Chinese Twitter,” after the 2010 Yushu Earthquake only 4% of the messages related to actions that individuals could or needed to take (Qu et al., 2011).

Whereas, 25% of the messages were basically Yushu situation updates, many from secondary sources. Similarly, during the Benghazi consulate attack the most dominant tweeters and the majority of the relevant data was prodiuced by news agencies (Carley et al., 2013).

First responder organizations are increasingly turning to social media (Cohen, 2013). They use it to identify actionable needs and orient the response, gauge the scope of impact of the event, provide information to the public, track and mitigate firestorms, counter false information, and to identify potential secondary disasters before they occur (Cohen, 2013). Some NGO's spend time during and immediately after disasters monitoring social media to identify specific individuals and subgroups who have needs that might be missed by traditional approaches and then providing information about resources. They make use of socio-cultural terrain information to self-organize their response and to help others self-organize, thereby supporting community resilience.

Crisis Maps and Sense-Making

Crisis Maps support enhanced sense-making which is a critical activity in crises and disasters (Gephart, 1993; Weick, 1993). In general, sense-making is a collaborative process where shared awareness and understanding are created out of a diversity of individual experiences and objectives (Weick, 1988; 1995). Coordinated crisis response requires such sense-making at a number of points – staging to respond to the upcoming event, estimation of the scope and prioritization of issues, recognition of stage of response, and so on. Crisis mapping technology brings together technology that supports collaboration, visualization and analytical capabilities that enable making sense of data, in part by supporting the automatic identification of anomalies, trends, and through estimation of scope and needs. A key point, is that such technology supports this collaboration using an unprecedented level of data, at a speed of interpretation not heretofor possible.

Crisis mapping technology holds the promise of allowing for a rapid and scalable enviroment in which decisions can be made collaboratively by a large group of actors with less formal coordination and possibly no history of coordination. Identification (Weick, Sutcliffe, and Obstfeld, 2005) is achieved as respondents post what they can do and where, and needs of victims are posted. The use of streaming data and continual update reduces interruptions and supports on-going coordination on the fly. The traditional sense-making activity of individual respondents reading news stories and visiting sites to extract cues (Salancick & Pfeffer, 1978) is augmented with auto-extracted cues on needs and services, and insights into events through anomaly detection and trend analysis. Using advanced computational technology larger sets of constituent actors can be supported and more complex situations addressed (Snowden and Kurtz, 2003) thus enabling sense-making to occur at an unprecedented scale and speed. This means that the victims needs are being addressed faster and problems mitigated thus reduciung costs and loss of life. It also means, that the set of responders need not be known in advance and can in a distributed fashion join and leave the crisis response process without harming the overall organizational response.

In traditional organizations sense-making can fail as the unequal distribution of power gives some participants greater voice. In principle, crisis mapping technology, particularly when crowd-sourcing tehcniques are used, increaes the potential number of stakeholders as barriers to entry are reduced (all one needs is internet access), enables those with little structural power to have greater voice, and increases the number of opportunities for engaging in sense-giving and sense-making to all participants. These technologies enable generative political processes (which allow individuals and groups to create change (Giddens, 1994)) resulting in potentially more democratic decision making and decision making that is sensitive to the local cutlural context. Thus Crisis Maps not only provide computationally enhanced sense-making but also greater involvement, a more level playing field, and higher sensititivity to local concerns. This is critical for establishing trust and

enhancing community resiliency (Comfort, Boin, and Demchak, 2010; Bruneau et al., 2003; Rose, 2009; National Academies, 2012) through the creation of a web pf practice. It should also mean that at-risk groups such as minorities, children and the elderly have a greater voice and their needs become more obvious to the responders. In this way contextual rationality (Reed, 1991) is made possible through local participation and cultural sensitivity. The expectation is that the higher heterogeneity among particpants and the de-coupling of structural power and voice will increase the accuracy of the sense-making process.

Sense-making is vulnerable to incomplete data. In the world of big data, Crisis Maps are leveraging more data from more sensors thereby making the overall data on the crisis more complete and more certain. A consequence would be that the distance between whata is plausible and what is factual will be reduced. Advanced visualization and analytics can be used to infer missing data, reduce uncertainty and enable interpretations to be based on broader more accurate information. Traditionally, in crisis, decisions are often made based on personal judgement given the lack of ability to monitor the situation and lack of feedback reduces the speed of decision making (Hale, Hale and Dulek, 2006). Crisis Map technology should fundamentally alter this logic by providing an environment of continual feedback and situation monitoring, thus providing increased situation awareness. A side benefit would be increased community resilience which derives from the provision of accurate and timely information and results (Quarantelli, 1988; Topper & Carley, 1999; Lin & Carley, 2003).

Crisis Map technology allows teams to form on the fly. Teams with little shared history often suffere a sense-making collapse (Weick, 1993). Due to the use of enhanced communication channels, and the embedded participatory decision making support, Crisis Maps should enable the overall organizational system to be more resilient. Enhanced communication and the structure afforded by putting things into and retrieving data from a Crisis Map, should serve as team-building

experience. Futher, Crisis Maps could support interaction at the role-to-role level such as police to firemen and are agnostic as to who specifically fills that role. This builds team experience by enabling the respondents to make use of knowledge of other respondents in general categories. Finally, Crisis Maps are expected to provide a transparent organizational environment where critical information can freely circulate thereby enablign a uniform direction to develop and supporting trust.

Crisis Maps as Organizational Design

The role of organizations in crisis response and disaster management has been widely studied (e.g, Quarantelli, 1978; Dynes and Quarantelli, 1968; Drabek, 1986; Dynes, 1970). Generally, crisis response is recognized as a process in which the responders operate as a networked organization, and decision making is done in a distributed (Hutchins, 1991), and recognition-primed fashion (Klein, 1998). In this process, coordinative structures often emerge based on either historical or legislated agreements or power within the local context. Understanding the ”organization” that responds is an exercise in mapping the web of affiliations and participation as it unfolds. Crisis Maps are a means of mapping out this web, enabling individuals and groups to become participants in this web, and monitoring the activities of this web. As such, the Crisis Maps become the representation of the organizational design in the crisis context, the tool for designing the crisis response organization, and the technology for supporting boundary spanning activities. Already, social media which is a key component fo a Crisis Map, has been shown to support boundary spanning activities (Sutton, Palen, and Shklovski, 2008).

Crisis Maps track information on the socio-cultural terrain. This is defined in terms of the who, what, where, when, how and why of importance in a crisis situation and the relations among these. Crisis Maps are used both for planning inter-organizational response, and as the basis for on-going

coordination, and self-organizing that goes on in a crisis. The perspective on organizational design inherent in Crisis Maps is distinct from traditional approaches in that it is more network based focusing on relations, high dimensional, dynamic, and crowd-sourced. The fact that Crisis Maps are dynamic make them particularly effective for the design of the reponse, as in crisis organizations often need to change their design to be effective (Lin et al., 2006). Traditionally, crisis response groups when designing a coordinated response did so in a very adhoc fashion relying on historical relations, availability, and formal agreements. Moreover, the focus was almost exclusively on who would work with whom and who would provide what in general. Shared histories of co-responding served as the basis for trust relations rather than an analytic assessment of the response process and needs.

Organizational theorists have described organizational designs in terms of networks discussing networks within organizations (Malone, 1987; Krackhardt, 1994), networks of organizations (Mizruchi,M. S. and Galaskiewicz, 1994), and the networked organization (Baker, 1992). In the crisis response area, the responders are often viewed as a network (Stephenson, 2005). Such networks often are seen to include networks among decision makers both formal and informal (Krackhardt and Stern, 1988), networks linking decision makers and tasks (Malone, 1987), and knowledge networks of who knows what (Borgatti and Cross, 2003). This type of high-dimensional network with multiple types of nodes (e.g., decision makers, tasks, and knowledge), and multiple types of links (e.g., who needs what, and who provides what) are often referred to as meta-networks (Carley, 2002).

Crisis Mapping can be thought of as an organizational design tool within this network tradition. By characterizing the socio-cultural terrain as a set of interlinked networks, the Crisis Map is effectively enabling respondents to create an organizational design for crisis response on the fly. Within this design the who, what, where, how and when take on particular meanings. Critical

meanings are described in Table 1. Each of these entities are in effect, a type of node in the emerging organizational design.

Table 1. Classes of Entities in a Crisis Map	
Who	Victims, Respondents (e.g., NGOs, military groups, firemen, police, medical groups)
What	Activities done by respondents (e.g., provide food, repair roofs)
How	Needs of victims, Resources available to fill needs
Where	Location of victim, Location of resource support
When	Time at which need is posted, Time at which need is filled or resources deployed

In the Crisis Map, and so the overall organizational design, specific entities are linked to specific other entities forming networks. For example, specific victims are linked to specific needs as when, for example, Mrs. Smith tweets that her daughter is missing. The critical networks are shown in Table 2. Note, in general, time is used to ”stamp” the links in the network with when they occur and so are more of an attribute than a type of node.

Finally, a Crisis Map, unlike the traditional organizational design as network, is explicitly dynamic. The response design changes as the needs change and as different resources become available. Moreover, Crisis Maps support the idea of design as, not only emergent, but as crowd-sourced. That is, particularly with respect to NGO’s and local stakeholder groups, the role of these organizations in the overall design of the response effort is to a large extent the result of a negotiated role, or a self-defined role, in part due to the volunteer nature of the these organizations.

Table 2. Networks in a Crisis Map		
Who	**Who**	Support: Victim to Respondent Collaboration: Respondsent to Respondent
Who	**What**	Activity: Respondent to Response Task
Who	**How**	Needs: Victim to Need Capability: Respondent to Resource
Who	**Where**	Victim Map: Location of Victim Respondent Map: Location of respondent
What	**How**	Usage: What activity requires what resource
What	**Where**	Response Map: What activity is needed/done where
How	**Where**	Needs Map: What need is where Resource Map: What resource is where

There are a number of challenges in collecting, collating and using the data in a Crisis Map. Many of these are the challenges of dealing with big data and still others are associated with the nature of information in a disaster situation. Identification of the relevant who, what, where and how can be difficult. Consider now some of the sources of difficulty.

Potentially any person in the affected region is a victim; but, in reality many may not need aid. When social media or news is used to identify victims care has to be taken to avoid misclaimants, and those presenting hoaxes. Further, members of key at-risk groups such as the elderly, children, and the disabled may not have access to or use social media. Thus other methods need to be used for identification such as census maps and local information on the region. Using data from these diverse sources presents a data fusion problem. For responders the situation is less complex. Traditional and large responders such as the Red Cross, FEMA, the US Coast Guard, the US Army,

firemen and policemen, often put out regular situation updates and are tracked by news agencies. Many even run there own social media broadcasts. However, best practices as to how to use social media, and how to post what resources are available are still in development. Thus ther eis no uniform presentation of information. Many smaller and local responders are predominantly volunteer organizations. In many of these cases, whether they present information on line depends on the skill sets of the personnel and whether they have time to put things on line. A final difficulty is that secondary groups often send out messages through the news or social media about the responders. However, typos, mis-spellings, use of alternative names or acronyms, create a situation where it is difficult to merge together all those references to the same responder.

For needs and resources there are additional difficulties. These needs and resources are often described in very disparate ways, and often in multiple languages. All references to the same type of need or resource to be collapsed into that type of need or resource. But this has to be done quite carefully, as often there are related terms that might make sense to collapse into it, but in fact are not disaster related. For example – it makes sense to collapse food, providefood, into food. But you might not want to combine this with hungry as people when tweeting about whre they are going to dinner often use the term hungry. Disambiguating calls for help and the need for food, from general class about food is a critical challenge. Note all of these challenges become monumental when you recognize that the data is huge and the disaster related data within this is relatively tiny.

For locations, a key problem is that data is often not provided with geo-tagged information. For example, less than 10%, generally less than 1% of tweets are geo-tagged. While research is underway to discover locations based on images, slang, etc, it is still operationally difficult to tell where ther data is coming from. In that sense, responders need to use those few calls for help that are geo-tagged and treet it as a possible signal that there is a greater need in that area than just the one tweeter. Whether or not this is true, is an empirical question that is under investigation.

Another critical issue here is that some people will send out messages that appear to be calls for help, or complaints about respondents, that are just hoaxes. Such data needs to be identified and removed rather than added to a Crisis Map.

Another critical point, is that depending on the type of crisis or disaster there may be no power, or it may be intermittent. Thus, critical information that could be sent out to Crisis Maps cannot be sent by victims when their power runs out. To further understand these challenges the current state of the art in Crisis Mapping is discussed.

Big Data for Crisis Mapping – State of the Art

Data for Crisis Mapping is big because it is multi-dimensional and time variant as in tracking the flow of all cars in a city as they evacuate cross indexed by the type of car and the type of occupants. The data is big because the data of interest is "hidden" in a larger data stream as in tracking the potential for violence associated with the Kenyan elections using the Twitter firehose. Currently, there are a growing number of technologies both commercial off the shelf (COTS), government off the shelf (GOTS), and university tools for building mashups, collecting social media, processing the data as networks, visualizing trends, extracting sentiment and key events from large data streams, placing data on maps, and so on. These tools are becoming increasingly robust, able to scale to larger data streams, and easier to use. Many university tools are as robust as the commercial tools. Key difficulties include: these tools are so new that few people know they exist leading newcomers to reinvent similar tools; funding to create such tools is negligible; the existing tools do not interoperate well; and free access to sufficiently big data to test the tools is difficult due to cost and sharing restrictions given the licensing agreements of most data providers (e.g., Twitter data cannot be shared and is costly). The use of big data to study crises and to provide information during crisis, is part of an emergent field of crisis informatics.

Most users, and would be users, are so unfamiliar with the kinds of data available and the meaning of the processed results, that they would rather use the tools to play with small data sets, than actually watch and learn with the real, big data. Proponents get excited by finding "the magic tweet" – the one out of thousands that has relevant content. But finding the magic tweet is not a sustainable endeavor with big date where there could be millions if not billions of messages across diverse media to sift through. Even if the users wanted to look at big data, most of the tools don't handle the full volume of data from anyone media, let alone multiple media. One reason for this is that most data "publishers" such as Twitter and Facebook have APIs that limit automatic access to published data to a small percent of its volume, e.g., one percent. For most tools, even if they could get complete data, they could not handle it. In a typical test scenario, data from events are replayed back to the tools. Many analysis tools, cannot handle streaming data such as you get with social media; although mappers like Ushahidi and Google maps can. Many tools expect the data to be "chunked" into meaningful units such as 4 hour blocks. To provide alerts, data needs to be stored so it can be retrieved for analysis and the behavior of today compared with the past. However, most databases don't scale for big data, and even fewer database designers understand how to set up scalable databases such as Oracle or PostGres to handle this type of high multi-dimensional temporal data. New database structures for large streaming data are currently in development.

Algorithms exist for processing and visualizing most of the data however, some of the most promising do not scale well – e.g., they scale as N2 (i.e., the number of units of interest squared such as the number of people who tweet squared) or higher. Many algorithms are not decomposable for cloud processing, i.e., they cannot be parallelized. For most crisis situations the data of interest is "hidden" in the big data, algorithms and visualizations for searching and capturing the data of interest, and visualizing just these data are more critical than algorithms for summarizing the overall big data. In general, once the critical data has been identified within the mountain of

data, current algorithms for analysis and visualization are sufficient. Research is focused on summarization but need is focused on identification.

Much of the data used in Crisis Mapping is textual or visual. Examples include tweets with attached urls for u-tube videos. While some tools exist for text mining they are insufficient from a Crisis Mapping perspective. Current tools let you track key words, but don't automatically identify all synonyms or identical words in other languages, making it difficult to automatically e.g., find all requests for medical supplies. Current tools have sentiment tracking; however, this is done on the basis of adjectives and adverbs only, tend to only rate a message as pro or con, and so do not provide a nuanced enough understanding of the emotional landscape. Current tools let you identify topics using various clustering; however, these topics are often non-intuitive and there is no ability to mix known and unknown topics. Most of the text mining tools can operate in a distributed fashion, e.g., in Hadoop, and so are relatively fast even for big data. The state of the art in image and video processing is even more primitive. Few tools even track that images and videos exist or the meta-data for such data. Tools for searching, comparing, doing location and person identification given images are in development but far from everyday use. Nevertheless most Crisis Mapping tools will auto-locate information on maps when latitude and longitude are available or inferable, popup images, and link to videos thus giving the users a more informed and data rich understanding of the crisis situation.

One of the keys in Crisis Mapping is addressing questions such as who needs what where, or who is working with or aligned with whom on what issue. To answer these questions, analysts need to characterize and understand the socio-cultural terrain. Understanding the socio-cultural terrain means tracking who, what, where, how, why and when. Thus a key is extracting and analyzing the meta-network (multi-dimensional dynamic networks) from data and assessing change in this. Most current social network technologies do not support big networks nor meta-networks. Even fewer

support dynamic networks. One of the few technologies that supports all this is ORA. But, even ORA is too slow networks with over 1,000,000 nodes. Further, network algorithms designed for big data are generally not valuable for Crisis Mapping as they focus on global network properties rather than the specific socio-cultural and crisis related factors that need to be assessed. In other words, calculating the overall network features for big data can be done quickly; but, providing the detailed node or motif level metrics needed for Crisis Mapping is too computationally intense for big data.

Big Data Applications and Impact – for Crisis Mapping

Crisis Mapping technology for processing, analyzing and visualizing big data have a number of applications. An obvious application is in providing first responders with a firm and up-to-date understanding of who needs what where in the case of natural disasters. When these systems are coupled with indications of response they can also be used by the public to know where to go to for help. Utilization of big data, particularly that coming from social media has the potential to decrease time to respond, reduce workload on first responders, and consequently increasing the likelihood of saving lives and minimizing damage to property.

High levels of participation afforded by these technologies coupled with big data and analytic procedures enhance the ability of responders to anticipate events that could build into disasters in within the current crisis scenario, to seperate the wheat from the chaff and so identify actual emergencies rather than simply responding to noisy requests for aid, and to characterize needs to enable a more planned strategic response rather than reactive response. For example, adavanced text-mining, pattern-identification, and machine learning techniques support the characterization of messages in terms of topic and priority. For example, analysis of sensor data coupled with weather data enables responders to determine the immediacy of various needs such as the need for different levels of shelter. By enabling the responder to identify needs, despite the weakness of the signal,

big data and the associated analytic engines promote the creation of a shared culture of reliability where responders empowered by more accurate data can actively engage in the sense-giving process. Moreover, Crisis Maps could be designed to preserve data enabling play-back and training. This could further support the development of a culture of reliability by enabling heighted training, role-playing, and enabling responders to learn techniques for anticipating future crises.

Crisis Maps have the potential to computataionally enhance sense-making and participation in the sense-making process. Crowd-sourcing, web-based visualizers, geo-based visualizations, and the use of social media to add data to a Crisis Map could be used to create a participatory system in which responders and communities join together in a creative commons to mitigate the impacts of crises and disasaters through shared data collection, interpretation, and problem solving. Increased access means that under-represented and at-risk groups have more opportunities to make their needs known and do not need to rely on advocates. Translation systems, visual data provision, speech technology can all be added to a Crisis Map to support getting information to those at risk. The participatory nature of Crisis Maps and the use of local data thus combine to promote the creation of a shared culture of resiliency and respect.

Another application is disaster preparedness and early warning. For example, coupling in event warning technology such as ocean floor sensor grids to provide warning on tsunamis with information on current built environment with that on people movement available through SMS, systems to support early warning and chart sensible evacuation are possible. In the realm of political crisis, such systems also have the potential to track political tendency toward violence or riots associated with social or political events such as world cup soccer final tournament, Olympics, or political elections. Economically, one of the more profound impacts may be the ability of these systems to provide early warning for epidemics and pandemics, and for tracking and assessing health related issues. The key is the combination of crowd-sourced data, with sensor data, with

general background information fused to address key issues made possible by big data algorithms for streaming text and video information, distributed storage, and cloud computing.

Foreseen Challenges Associated with Crisis Mapping

In the area of Crisis Mapping the challenges are both social and technical. Social, policy, scientific and engineering solutions are needed.

The National Research Council has run two studies (2013; 1996), years apart, on the challenges and state of art in big data. Between those two studies, what was meant by big has grown slightly, but more importantly the challenge and promise of big data has come to be recognized in more disciplines. That being said, most of standard technical and scientific challenges still remain: algorithms don't scale, sampling biases are not well understood, search and retrieval still need to become more refined, visualization is poor, appropriate data base structures do not exist, and so on. That being said, the area of Crisis Mapping presents some specific challenges over and above these ubiquitous big data challenges. These include: social media providers limit access to and analysis of data, critical crisis information is often invisible against the wealth of other data, much of the data produced in or during a crisis is not operationally useful, multi-lingual use and production of the data needs to be supported, information grows stale very quickly and rapid response is needed based on data the is provided only a few minutes or hours prior, providing information that can be valuable to the responders and analysts and can support resiliency can have a dark side by providing guidance to others about system vulnerabilities, and the "data" and "data source" can themselves be security threats from a cyber-perspective. Addressing these challenges requires new theory, new methods, and in some cases new policies.

As an example, consider the data access challenge. Much of the big data of use for Crisis Mapping is actually not from social media such as Twitter. Indeed during and after a crisis social media use, like Twitter is barely a fraction, of the volume of crisis communication in SMS and

email (Munroe, 2012). Such data is not generally available to responders unless it is sent to a Crisis Map such as Ushahidi. In contrast, most social media data, such as Twitter, is provided under the creative commons license and so is in the public domain. As such, it can be harvested and used. However, most analysts simply cannot access the volume of data available. As noted data publishers limit how much data can be accessed by any one data call. These data calls, are in essence, collecting a sample of the data. In general, these samples can be quite different than the underlying full data and may even lead to misinterpretation of events (Morstatter et al., 2013). Little is known about how to conduct such samples to get accurate coverage. There are also companies, such as GNIP, that collect and resell data from the data publishers, e.g., they collect and resell Twitter data and other social media data. In many cases, the data bought is still a sample, though in this case the analyst has less control over the sampling procedure. Further, the cost of such data tends to be prohibitive for most researchers. Accessing such data is a strategic advantage. The data access challenge is thus in part an organizational challenge – who owns the data – and in part a technology challenge – technology limits on acquiring, storing, and searching such data – and in part a scientific challenge – development of sampling theory and bias estimates for big data.

A second challenge with respect to big data that is particularly difficult for Crisis Mapping is accurate sense-giving. Sense-giving is the attempt to influence the sense-making process and the meanings that are constructed (Gioia and Chittipeddi, 1991). With advanced computer technology and social media there are increased opportunities to create misinformation. During Sandy, fraudulent news items and images complicated the identification of actual needs (Bello, 2012). Further, social media is enabling information to go viral (Pfeffer et al, 2013), both true and false information, creating cascading effects that can ruin reputations, mislead response efforts, and increase the difficulties faced by first responders. For example, Harvard Humanitarian Initiative's (2011) study of the Haitian earthquake response suggets that as many as 70% of the 4636 messages

appear to contain errors, including requests to locate victims by people who knew the victims to be dead. Often during a crisis intentional misinformation is spread. For example, during Superstorm Sandy @comfortablysmug was spreading false information about the events in New York City. This misinformation can misdirect response efforts. For example, Twitter users and Redditors incorrectly identified a missing Brown University student and individual mentioned on a police scanner as the bombing suspects for the 2013 Boston Marathon Bombings (Madrigal, 2013; Weinstein, 2013), leading to a brief and extreme online witch-hunt for which Reddit administration later apologized (Martin, 2013). The ease of creating and spreading misinformation means that any individual has the possibility of influencing the sense-making process and redefining the organizational reality for the responding organizations. Sense-giving contests (Maitlis and Lawrence, 2007) could result leading to misapplications of resources, fraud, corruption, loss-of-life and delay in providing aid to those in legitimate need. Again the challenge is social – developing social norms against misinformation, legal and law enforcement – developing appropriate laws and law enforcement strategies appropriate for big data, and scientific – developing procedures for discerning misinformation rapidly and mitigating the effect of such misinformation. The mitigation strategies, however, are likely to contribute to the data available. For example, the Boston Police published the facts of the marathon bombing case to Twitter in an attempt to counter rumors (Keller, 2013). All-in-all, for the emerging field of crisis informatics, trust in data and trust in data source is a key issue (Hagar, 2013).

Interestingly, the idenfitication of false information may be aided by crowd-sourcing. Crowd-sourcing is the ability of individuals, often large numbers of individuals, to contribute to answering an overall question through the internet. Volunteers world-wide scan photos to find missing people after plane crashes and in other search and rescue operations (e.g., Marks, 2007). In the case of @comfortablysmug, many of his tweets were identified as false by other Twitter users. One journalist, Stuef, tracked images from @comfortablysmug's Twitter profile to his YouTube vide and

then using this information was able to track down @comfortablysmug's true identity (Kaczynski, 2012; Stuef, 2012). The scientific challenge is developing an understanding of the strengths and biases of crowd-sourcing; the social and policy challenge is developing the appropriate venues to make use of such crowd-sourced information in a crontrolled and principled fashion while not exciting the crowd to vigilante actions against innocents.

A key scientific challenge is the development of metrics that provide indepth analysis of big data, that scale well, and enable the idenfication of critical actors, needs, locations, and so on. Many of the needed metrics are for network data. For example, there is a need for scalable temporal and network approximation algorithms that support detailed analytics and can be used with streaming data such as the k-centrality algorithms (Pfeffer & Carley, 2012a) and incremental algorithms (Kas et al, 2013a; Kas et al., 2013b). Metrics are needed that can be used to create a multi-media early warning system for social change, crisis events, outbreaks of violence, and pandemics. Early work shows that while twitter warnings can presage news warning by exactly a day for some activities, details and other activities occur earlier in other media. Finally, automated context based scalable algorithms for searching big data and data merging techniques for cleaning the big data to produce meaningful results are needed, along with associated metrics for estimating the bias resulting from the search, merging, and cleaning strategy.

Another challenge has to do with cyber security. Today, most malware are web-based attacks. Many of these attacks are through attaching malware or viruses to web-pages, social media messages, and so on. This means that the meer collection of data may in itself lead to the data collector becoming infected. Crisis Mappers are thus at risk of both being attacked and in turn infecting others inadvertently. The potential for turning a crisis into a mega-crisis through such devices is increasing. Numerous scientific, social and legal challenges are centered on mitigating this possibility.

Finally, it is not well understood how to design and build Crisis Map systems. There exists little scientific guidance on the design of decision support technologies for crises that rest on knowledge managemnt and sharing technologies informatted with social media (Yates and Paquette, 2011). How Crisis Maps are similar to or distinct from other enterprise systems with respect to usability, scalability, portability, open standards, durability, and maintenance before, after and during disasters is not known.

Summary

Crisis response and disaster relief, whether for natural disasters or human created crises, is an area that is being transformed by the use of big data. Today, the technology to support this effort is emerging and improving faster than is a clearing house for information about that technology. Most responders do not know about the technology currently available and most technology developers are unaware of others work in this area. The technology in this area is increasingly geo-temporal, but there is little understanding of what can be done other than putting the information on maps. Nevertheless there are many serious gaps. Four are worth highlighting. First, data publishers do not necessarily store the data nor provide it. Second, there are no common standards for the data, or for parsing it, particularly in terms of relevance to crisis response such as the need for food, water, shelter, medicine, locating missing persons, and preventing corruption. Third the data is increasingly including images and videos that cannot be parsed. Fourth, analytic techniques for identifying key issues, actors, needs, and so on are rarely part of the available tools. Or in other words, with the current technologies, we can collect data but we cannot always share, what we can share we cannot read, what we can read we cannot interpret, what we can interpret we cannot use to provide actionable intelligence. Addressing these challenges requires new theory, new methods, and in many cases new policies, laws and even organizational forms.

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