Spatial Temporal Data Visualization In Emergency Management : A view from data-driven decision

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ABSTRACT

Recent years, extreme events caused a great loss of human society. Emergency management is playing a more and more important role in handling disaster events. With the raising of data-intensive decision making, how to visualize large, multi-dimension data become an important challenge. Spatial temporal data visualization, a powerful tool, could transform data in to visual structure and make core information easily be captured by human. It could support spatial analysis, decision making and be used in all phase of emergency management. In this paper, we reviewed the general method of spatial temporal data visualization and the methods in data-intensive environment. Summarized the problems of each phase of emergency management and presented how spatial temporal visualization tools applied in each phase of emergency management. Finally, we conduct a short conclusion and outlook the future of spatial temporal visualization applied in data-driven emergency management environment.

CCS CONCEPTS

• **General and reference** → *Surveys and overviews*;

KEYWORDS

emergency management, spatio-temporal visualization, review

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1 INTRODUCTION

Since the beginning of 21st centuries, mankind are facing more and more dangers and challenges, those emergency event caused a great loss of human society. Some of those hazards come from nature, like earth, some come from public healthy and some come from human society. According to International Federation of Red Cross and Red Crescent Societies, in last decade, globally, there are 771,911 people lost their lives in natural disaster, about 1 billion people was affected. Natural disaster also caused about 1 billion dollar loss, worldwide[1]. Natural disaster is becoming one of main challenge to human society. Whats more, several infectious disease break in last decade, hundreds of thousands people was killed by those virus. In this situation, emergency management become more and more important.

Emergency management is defined by Hoetmer as the discipline and profession of applying science, technology, planning, and management to deal with extreme events that can injure or kill large numbers of people, do extensive damage to property, and disrupt community life[2]. Based on temporal dimension of disaster event, one famous framework called comprehensive emergency management(CEM)[2]. It organize the emergency management process into a cycle of four phases: mitigation, preparedness, response, and recovery, as shown in figure, The actions of each phase should be made based on multiple data, in this field, visualization tools could effectively transform data into human-friendly interactive graph which could easily be understood. Based on this, Visualization technology has been used throughout all phases of the emergency response cycle.

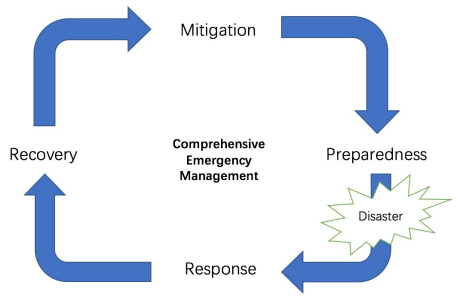

Figure 1: Comprehensive Emergency Management[3]

Traditional emergency management is always model-driven. Since the raise of the fourth paradigm: data-intensive scientific discovery[4], data driven decision making become more and more important. It is critical to visualize data in a direct way to represent data attributes. Through all phases of emergency management, many of the critical problem that arise are inherently spatial. Whether an analyst is assessing the potential impact of a hazard, or an emergency manager is identifying the best evacuation routes during a disaster, or a civil engineer is planning a rebuilding effort following a disaster, all of these individuals face tasks with a strong spatial component [7]. For this reason, spatio-temporal data visualization technology is a valuable framework to handle emergency management.

Spatial temporal visualization is one import area of data visualization. A picture is worth than thousands of words. About 80% of the information obtained from the outside world comes from the eyes.[5] Using data visualization tools could make data features intuitively captured by decision maker. The general process of data visualization is shown as Figure 2, first, transform raw data into table formats and then using visual mapping method to change data table into visual structures, finally, view transformations integrate visual structures into views which human can see. Visual mappings is the most important step in these three steps.

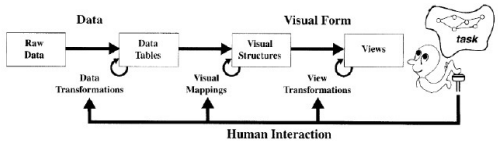

Figure 2: information visualization reference model[5]

It makes data visualization as a powerful tool which could transform data into vison and make data feature easily captured by human. In the emergency management environment, many data containing geo-location and temporal tag, choosing a right way to present data will make the situation quickly be understood. It could support decision making.

In this paper we will make an analytics review spatial temporal data visualization technique and its applications developed in emergency management. The remained section is arranged as below: Section 2 describe the traditional spatial temporal data visualization technology and data-driven environment spatial temporal data visualization method, Section 3 show the visualization needs of each phase in emergency management, Section 4 describe the examples of visualization methods applied in emergency management and finally we conduct a short conclusion and outlook

2 SPATIAL TEMPORAL VISUALIZATION AND EMERGENCY MANAGEMENT

Spatio-temporal data was defined as data with geo-location and temporal tags. In the condition of sensors and mobile device widely used, spatio-temporal data become easily gathered data[6, 7]. In the era of big data, because of rich spatio-temporal data, spatio-temporal data visualization is becoming a hot research spot. How to combine the spatial and temporal attribute, present the relationship between spatio-temporal attribute and other attributes, combine the spatio-temporal data visualization and cartographical, visually show the multiple dimension of data and present real-time data in a visual method, are important research areas.[8]

There are a lot of methods focus on how to present spatial temporal data. In the data-intensive environment, combining big data analysis tools and support collaborative visualization is a important part of modern spatial temporal visualization methods.

2.1 General Spatial Temporal Visualization Methods

The basic idea of data visualization is to present every features of data with basic element of graph. That means a graph could present a large volume of data and could reflect multiple data dimension, which could make people analysis data from various perspective[9]. MacEachren concluded the research challenges in spatial temporal visualization[10], Andrienko reviewed the spatio-temporal visualization by tasks and solutions[11]. There are many tools were built to visualize spatial temporal data[12–14]

The widely used methods of spatial temporal data visualization methods include spatial data visualization methods, temporal data visualization methods, spatio-temporal data visualization methods.

Spatial data visualization methods. Spatial data visualization have a long history[15]. Spatial data inherently have geography component. There are many visualization technology based on map, traditional maps are static, it help human know spatial information for centuries but it is hard to use static map represent multiple attribute of data. Comparing to traditional map, computer-based spatial visualization tools have two new properties: interactivity and dynamic[11], which make the tools have ability to answer users questions and show object variation in given constrains.

Spatial visualization methods, with interaction, like scatter map[16], heat map[17], not only could use the shape or color of one point could represent multiple attribute, but also could add information into point when you click your mouse like in Echarts, D3 and R.

Temporal data visualization methods. Time series data is a kind of widely used data. There are many ways to visualization the time series data, like histogram, line chart or amination technology. Daassi made a taxonomy of temporal data visualization[18]

Parallel coordinates, another widely used temporal visualization technology, builds reflection between ordinates on which draw line to represent data attributes. It was firstly used to represent multi-dimension data[19]. It is also could represent multi-dimension temporal data with multiple data attributes.

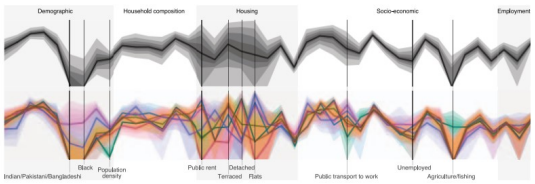

Figure 3: parallel coordinates[20]

Spatio-Temporal data visualization methods. To reflect the relationship between location variation and time changing, one effective method of spatio-temporal visualization called flow map[21] which could compromise event temporal attribute and map. One example of flow map is the visualization of Napoleon attack Russia in 1812[21] shown in Figure 4, it used flow map technology to combine big events temporal attribute with location information reflected in 2D plane.

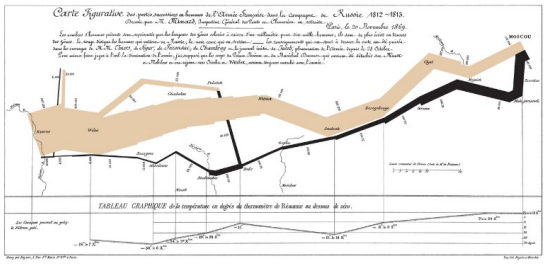

Figure 4: Napoleon attack Russia in 1812[22]

Space-time cube[23] is a widely used technology of spatial temporal visualization. Space time cube uses a 3D way to represent location, time and event .The cube has on its base a representation of the geography (along the x- and y-axis), while the cubeâĂŹs height represents time (z-axis)[24]. There are many system based on space time cube[25–27]. While the data volume is huge, the cube may be mix, Tominski use stack graph to multiple data attribute[28]. Space time cube has been used to represent GPS data, hurricane data and so on.[29]

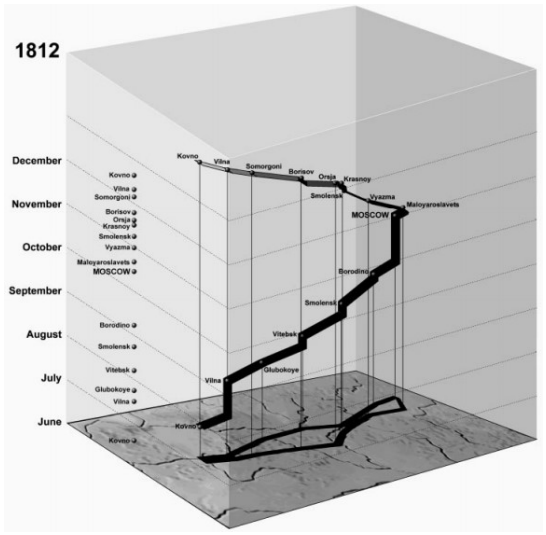

Figure 5: space time cube[30]

The technology of map animation exploits the capability of the computer screen to rapidly update its contents: changes in data are represented by changes of a display[11]. It is an import method of visualization spatio-temporal data[31]. On one hand map could directly reflect the location information, on the other hand animation could make temporal attribute easily understand. In cartography, temporal animation is a widely used method, it deals with the depiction of dynamic events in chronological order and depicts actual passage of time in the world. In a temporal animation, 'world time' (e.g. days, centuries) is typically proportionally scaled to 'animation time' (e.g. typically seconds)[32].

2.2 Spatial Temporal Visualization in Data-Intensive Environment

In the time of big data era, data-intensive environment and data-driven decision making become more and more important. Traditional visualization method facing new challenge. In this scope, data needed to be processed are so large that one single computer canâĂŹt deal with. Because of the volume of data, it is also hard to transmit data over internet. And with limit knowledge, in complex condition, decision always made by a group of experts[33], how to use visualization tools to support collaborative work is also an important problem.

Visualization methods based on cloud computing . There are two general ways to overcome the problem caused by big data, using statistic way to minimize the data volume[ref], the other way is to use more machine to handle more data. In this paper, we focus on the last way to conquer the change of big data. Hu et al review the general methods to process big data[34], Ren[8], Zhang[35]reviewed the technology of apply visualization tools into big data environment.

Visualization based on cloud computing combines big data technology and visualization technology. Generally, it use cloud computing technology to preprocess data, improve the data quality and generate spatial temporal data attributes. Then, it use visualization method to represent the features. Mao combine spark and visualization method develop a visualization system[36], Eldawy developed HadoopViz[37] based on Hadoop, Lu provide a framework for cloud-based visualization[38]

Collaborative Visualization methods. Collaborative visualization is the shared use of computer-supported, (interactive,) visual representations of data by more than one person with the common goal of contribution to joint information processing activities.[5] Guo developed a collaborative visualization architecture for spatial temporal data applied in emergency.[39], Hutanu think one of the most important issues in collaborative visualization is the latency. Hutanu developed a distribute system based on high speed network[40]

2.3 Spatial Temporal Visualization Tools

There are many valuable spatial temporal data visualization tools as open source program. Most of them have the basic methods of spatial temporal. And each of them have their own advantage and disadvantages. Table 1, shows some widely used spatial temporal data visualization tools

Table 1: open-source visualization tools

Name	Program language	Website
D3.js	Javascript	https://d3js.org/
Echarts.js	Javascript	http://echarts.baidu.com/
Matlibplot	Python	http://matplotlib.org/
Ggplot2	R	http://ggplot2.org/
Leaflet	Javascrpt	http://leafletjs.com/
Polymaps	Javascript	http://polymaps.org/
OpenLayers	Javascript	http://openlayers.org/
Kartograph	Python, Javascript	http://kartograph.org/
Exhibit	Javascript	http://www.simile-widgets.org/
Modest Maps	Javascript, Python, PHP	http://modestmaps.com/
Tableau	-	https://public.tableau.com/s/

2.4 Challenge in Emergency Management

Because of emergency management data have multiple features which makes data analysis facing a great challenge. In all phases of emergency management, the action of emergency management and event itself will generate huge volume data from multiple source such as government reports, news, tweets, satellite images, etc. and the data formats will not be uniformed. However, those data always contain geo-spatial information or could implicit location information.

Some emergency situation need to present real-time data for decision making and strategy making. For example, monitoring the water level of the river in order to know whether there will be a flood. If the data canâĂŹt reflect the real time situation, it will be meaningless. When an emergency event occur, like an earthquake, it is important to present the up-to-date information for rescuing people who suffering during the disaster.

Some situation need to be examined from a geographic perspective over time. For example, with a phenomenon like the Avian Flu virus, information about where and when deaths and illnesses are occurring is relevant input to policy decisions for public officials internationally and not only for officials in the locations where the illnesses/deaths are occurring. Actors at multiple scales must be informed about the spread of the disease to prepare accordingly, be kept aware of the effectiveness of preventive strategies in use by others, and understand the interconnected hierarchies of relevant events and information at many levels.

During emergency management cycle, decisions always made by a group of experts. It is also important that sharing information between different experts. Because of the multiple source of data, for supporting decision make will need domain experts in every aspect of data.

2.5 Spatial Temporal Data Visualization in Emergency Management

Facing the challenges of emergency management, spatial temporal data visualization is a great tool to support decision making, spatial analysis and sharing information. There are some challenges which are through all phases of emergency, like data volume, data dimension(see Table 2). Each phase also have some unique demand from spatial temporal visualization tools.

Table 2: general need and methods

Challenge	Method
Monitoring attribute change, like population, temperature, etc	Map Amination, space-time cube, map iteration, flow map
Represent multiple data dimension	Multiple-dimension scatter map with interaction
Represent very large data volume	Cloud visualization, high-performance visualization, partial visualization

Mitigation. In the phase of mitigation, the purpose of this phase is to elimination or reduce the probability of long-term risk to human life of property. Temporally, in emergency management this phase appear between disasters. In this phase, the main goal is to prevent disaster occur or forecasting the disaster[41, 42]. To achieve this goal, it is critical to make right mitigation strategy. That make using data to model the probability of a disaster occurrence become important. In order to support decision making and strategy making, there are a lot of visualization system being developing [13, 43, 44]. For example using spatial temporal visualization tools to represent the transmission of infectious disease like avian flu or zika virus, in this way to show the spread of disease support local government to make mitigation strategy[45].

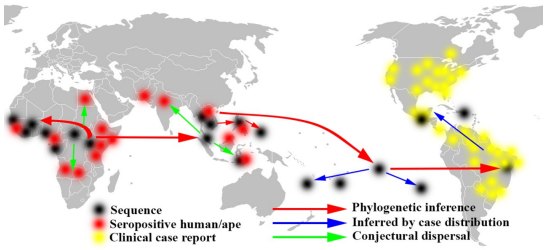

Figure 6: spread of zika virus[46]

Simulating the disaster is also useful for mapping hazard. The spatial temporal visualization system also could represent multiple data and simulating the extreme event occur to practice the response action[47].

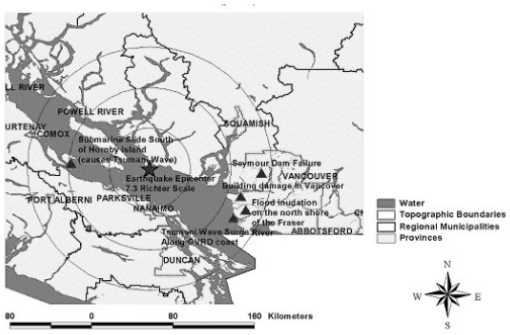

Figure 7: simulate the schenario of event location[47]

Table 3: visualization need in mitigation

Need	Methods	Example
Natural hazard assessment	Heat map, scatter map	Earthquake [48]
Find crsis cycle	Parallel coordinates,Temporal charts	Infectious disease[49]
Simulation disaster to make mitigation strategy	Map amination, space-time cube	Earthquake[47]
Finding transmission pattern	Flow map, scatter map, heat map	Infectious disease[50]

Preparedness and Response. In the phase of preparedness and phase of response. The two phases are right before and after disaster happen, in spatio-temporal visualization scope, there are many features in common. The plan made in preparedness phase is used in the phase of response[3]. When a disaster occur, response actions need to be taken quickly, which make decision maker face a hard problem, how capture the essential information from large amount and multi-source data in a short time and how to share information with other export. In the spatio-temporal visualization scope, that require visualization tools could quickly process multi-source, heterogeneous data and transform it into visual structure. Using cloud-based visualization technology, could conquer this problem[14, 37]

Using amination could dynamic reflect the time changing data over disaster occur. It could support response decision making and there are many examples show the spatial temporal visualization tools to support response activity. For example, Bengtsson tracking population change during earthquake[51]

To help disaster response, spatio-temporal visualization could support spatial decision. a famous example is John snow used map to find the source of cholera in London, 1854[52], which help government make decision to prevent citizen from cholera.

It could also be used to support rescue action and victim evacuation. In on hander it could show the real-time situation of extreme event to victim and help disaster victim understanding the current situation to find a safety way to escape from danger[53]. For example, the system that could help people find the shortest path to escape from emergency event.[54] On the other hand, it also could help rescue team find shorts path into disaster centers.[53–55]

Facing complex situation, response strategy always made by a group of experts. Spatial temporal data visualization could also be used to support collaborative sense-making in emergency[39, 56].

Table 4: visualization need in preparedness and response

Needs	Methods	Example
Real-time response visualization	cloud visualization	Emergency event[37, 39]
collaborative decision	Collaborative visualization	Emergency event[39, 56]
Rescue planning and victim evacuation	Map amination, trajectory visualization	Emergency event.[57]

Recovery. In the phase of recovery, the goal of this phase is to make repair damage. In this phase, it is important to map damage assessment. Visualization tools could help this process, and in the phase of recovery, it is also important to education people to save themselves. Spatial temporal visualization method inherently have the ability to help people understand

Table 5: visualization need in recovery

Needs	Methods
Rebuilt scenario	Map amination, map iteration
Damage assessment	Heat-map
Risk Education	Map amination, map iteration, space time cube

3 CONCLUSIONS

Since data-driven decision making become more and more important, it give spatial temporal visualization new meaning in emergency management. In order to conquer the challenge of modern emergency management, the technology of spatial temporal visualization is a necessary tool. In this paper we summarized the traditional spatial temporal method and its methods in data-intensive environment. Analysis the need of spatial temporal visualization in each phase of emergency management.

In the future, the spatial temporal visualization will play a more and more important role in dealing with disaster. As the boom of VR/AR technology, the improvement of interactivity, will make visualization method conduct knowledge more effective.

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