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Information visualization for emergency management: A systematic mapping study

Flávio Dusse[c,*], Paulo Simões Júnior[a,c], Antonia Tamires Alves[c], Renato Novais[a,b], Vaninha Vieira[a,c], Manoel Mendonça[a,c]

[a] Fraunhofer Project Center for Software and Systems Engineering, Technological Park, Salvador, Bahia, Brazil
[b] Computer Science Department, Federal Institute of Bahia (IFBA), Salvador, Bahia, Brazil
[c] Computer Science Department, Federal University of Bahia (UFBA), Av. Adhemar de Barros, s/n, Campus de Ondina, 40170110 Salvador, Bahia, Brazil

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ABSTRACT

Background: Emergency management (EM) refers to the ability to deal with emergency tasks in different phases and iterations. To do this, each task requires many and different types of information coming from several sources related to the incident. As people working in an emergency situation are generally under stress and have to make quick and effective decisions, they need to assimilate the received information in an easy and intuitive way. Information visualization (InfoVis) is the study of visual representations of abstract data to reinforce human cognition to understand these data through 2D computer screens. It is frequently used to analyze and understand the huge amount of multidimensional data produced in an emergency.

Objective: This study analyzes how researchers use information visualization tools to improve emergency management. Our general objective is to map the area examining both the scientific community and the contributions that have been published in the literature, aiming to provide information, such as: understanding how the area is structured, common practices in existing works, and research gaps.

Methods: A systematic mapping study was conducted to analyze the available information visualization tools and their applications in EM activities. A thorough search was carried out and a formal selection process was applied to gather all relevant articles on the subject. Selected primary studies were classified and analyzed with respect to their metadata and to answer eight research questions related to our mapping goal. In total, 196 studies were analyzed in depth.

Results: The mapping study identified the most common visualization techniques applied in emergency management, the common environments and phases where they are applied, identifying gaps and also possible trends in the subject. We found out that particular issues concerning emergency management are not fully covered by existing visualization approaches, and when covered, existing literature provides only partial solutions.

Conclusion: Our results provide a deep analysis on the application of InfoVis in the EM area, supporting researchers and developers in EM systems with insightful information on trending techniques in use, command practices and existing research gaps. We expect that these findings can support them on proposing new approaches to solve open problems in the area.

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1. Introduction

Emergencies or disasters have very complex and dynamic contexts where the response process should suit unforeseen situations without causing social harm or jeopardizing people's lives (ESRI Bulgaria, 2009). Examples of disasters that greatly stimulated research interest in this area were the attacks of September 11, 2001 (Schmemann, 2001), and Hurricane Katrina in 2005 (Treaster & Zernike, 2005), both in the United States, and more recently the Ebola epidemic on the Africa continent in 2014 (Sack, Fink, Belluck, & Nossiter, 2014), and the terrorist attacks in France in January 2015 (BBC News, 2015), among others.

Emergency management (EM) refers to the ability to deal with emergency tasks in all their phases and iterations, including the mitigation, preparedness, response and recovery. This is done by multiple agencies (e.g. Police, Firefighters, and Medical Services), named

* Corresponding author. Tel.: +55 71 3283 6273.
E-mail addresses: dussebr@dcc.ufba.br, dussebr@gmail.com (F. Dusse), paulo.junior@dcc.ufba.br (P.S. Júnior), antonia.tamires@dcc.ufba.br (A.T. Alves), renato@ifba.edu.br (R. Novais), vaninha@ufba.br (V. Vieira), manoel.mendonca@ufba.br (M. Mendonça).

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workforces, which do not work together routinely. In an emergency situation, these workforces usually use the concepts of Command and Control Centers (C&CC) to help in the coordination of the activities (FEMA, 2015). They have the mission to identify the emergency, either natural or man-made, and to use the provided means to protect life and property in the affected community. If the response actions exceed the response capacity of the affected location, the emergency becomes a disaster and the community needs extra resources of superior agencies (FEMA, 2015).

To be accomplished, each task in EM requires many and different types of information coming from several sources related to the incident (e.g. victims, eyewitnesses, workforces). Nowadays, C&CCs are equipped with breakthrough technologies, especially in visual systems, such as tabletops, e-caves and video walls (Engelbrecht, Borges, & Vivacqua, 2011; Ishida, Sakuraba, Uchida, Hashimoto, & Shibata, 2012; Sutcliffe, Gault, Fernando, & Tan, 2006). These technologies provide the C&CC with huge amounts of data (e.g. reports, images, audio, and video). As people working in an emergency situation are generally under stress and have to make quick and effective decisions in a short time, they need to assimilate the received information in an intuitive way, understandable and adaptable in their context. As well as this, if the information is not presented in efficient and intuitive ways, it can be hard to be analyzed by EM agents, or in the worst cases, it can generate misinterpretation.

Information visualization (InfoVis) is the field that investigates (interactive) visual representations of abstract data to reinforce human cognition (Mazza, 2009). It helps to map huge volumes of multidimensional data to the 2-dimensional screen of a computer. InfoVis approaches can therefore be effectively used to analyze and understand the large amount of data produced during an emergency and to present it in the different devices available in a C&CC.

To understand how InfoVis has been used to support emergency management, we conducted a mapping study of the area, following the guidelines presented in (Kitchenham & Charters, 2007; Petersen, Feldt, Mujtaba, & Mattsson, 2008). The main focus was to analyze how InfoVis approaches have been applied in the EM context, providing a comprehensive survey of studies that use visualization tools in some way to present and analyze emergency management information and classify the studies using facets derived from both areas. We collected data on three aspects: ((i) researchers and publication information, e.g. publication year and venue, authors and their affiliations; (ii) InfoVis characteristics, e.g. visual paradigms, visual attributes and mechanisms of interaction; and (iii) emergency issues, e.g. EM phases, EM types, EM environments, visualization data sources and the platforms of existing tools.

From this research, we identified that many existing tools were applied to support similar characteristics of EM. Identified gaps show that there are still many opportunities open for research in the area.

The remainder of this paper is organized as follows: Section 2 describes the method used for the systematic mapping undertaken in this study. Section 3 presents the main findings of the study. Section 4 presents a discussion about the results of this study. Section 5 considers the threats to the validity of this research. Finally, Section 6 presents our conclusions and the directions for future work.

2. Systematic mapping method

The systematic mapping study method is used to provide a structure for the research and its results (Petersen et al., 2008). In our work, we researched publications that present InfoVis techniques applied to the EM context. In Section 2.1, we explain the design applied to this study, including the main research question, eight specific research questions to refine the main one, the inclusion and exclusion criteria and the classification scheme. Section 2.2 presents the data extraction process for this mapping.

2.1. Research design

The first step in conducting a systematic mapping study is to search if a similar study has already been published in the literature. We initially looked for mapping studies, systematic reviews or surveys in the emergency management area with support of information visualization tools. We first searched in the digital libraries defined for this study (see Section 2.2.2) and in Google Scholar.[1] The most related works we found are the one from (Cutter, 2003; Van de Walle & Turrof, 2007).

Cutter (2003) analyses the use of Geographic Information Systems (GIS) in emergency management. Her work shows real case scenarios, described in different studies, where GIS based applications supported emergency response teams with their tasks, and it points challenges in the use of such systems from the point of view of both GIS scientists and first responders. It concludes that GIS community and emergency management practitioners would both benefit of a closer collaboration. Van de Walle and Turrof (2007) discuss the state of the art in emergency response information systems showing a series of studies in this area. They present the goals and conclusions of the studies and reach the conclusion that a previous statement, made by Turrof, remains true: “past and future objectives remain the same in crisis: providing relevant communities collaborative knowledge systems to exchange information”.

The above works relate to this mapping study in the sense that they analyze multiple studies on the use of software systems to support EM activities. However, their goal is to give an overview about the application or the benefits of such systems in a general way. No specific systematic approach is presented to select or to analyze the presented papers. Our work focuses in understanding the use of InfoVis in the EM area, following a strict protocol to search and extract information from the selected primary studies. Thus, to the best of our knowledge no other study systematically investigates how information visualization is being applied to emergency management systems.

We also asked specialists in both areas if they were aware of any work that could be used to support this research. The performed searches and the specialists’ did not present any work like ours. Since there is no similar study, the next step in conducting a systematic mapping study is to define a robust design. In this section, we detail the rationale used to plan the mapping study.

2.1.1. Research questions

The purpose of this work is to perform a systematic mapping study that helps to structure the field of research – InfoVis applied to EM – by identifying the relevant literature about the use of information visualization techniques employed in tools to support emergency management, through a main research question:

MRQ: “How do Information Visualization tools support Emergency Management Systems?”

This question is to characterize existing information visualization tools used to support emergency management and to identify the differences among them. These differences were classified according to a classification scheme (see Section 2.1.4) extracted from both information visualization and emergency management areas.

2.1.2. Refining the main research question

To answer the main research question, we formulated a set of specific research questions (RQ) which were classified in two groups: (a) understanding existing information visualization tools and their application to EM (RQ1, RQ2, and RQ3); and (b) the suitability of existing visualization tools for various EM activities (RQ4, RQ5, RQ6,

[1] https://scholar.google.com.br/.

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