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# Information theoretic approach to design of emergency response systems

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Abstract: Recent natural disasters have highlighted the need for disaster preparedness, planning, and management. Hurricane Katrina demonstrated the usefulness of Web sites in dealing with natural disasters. However, little is known about the necessary contents and structures of Web-based information systems for natural disaster management. In this paper, we focus on developing an ontology structure of elements for Web-based disaster management systems. Web elements are identified, following a grounded-theory approach, from an inventory of Web pages drawn from disaster management Web sites. Selected semi structured Data representation approaches are used to organize the resulting ontology structure, which consists of 2094 Web elements.

***Index Terms*—Disaster management, grounded theory, ontology design, qualitative analysis, schema integration, Web design.**

## I. INTRODUCTION

**From** the last decade to till, the largest three hurricanes, namely, Sandy**,** Katrina, Rita, and Wilma, impacted millions of lives [1]. Katrina devastated nearly 90 000 square miles. Rita struck within a month, damaging and destroying more than 350 000 residences [2]. The use of the Web in disaster recovery efforts demonstrated the usefulness of Web sites in dealing with a disaster. The ubiquity and asynchrony of the Internet make it a natural platform for information exchange and communication for managing mass crises.

Although there are many disaster-related Web sites, little is known about the necessary contents and structures of such sites. This paper presents a first attempt in developing an ontology structure of elements for such Web sites. We strive to answer the following research questions.

1) *What data representation approaches are suitable for developing an ontology structure of Web elements in Web-based natural disaster management systems (WB-NDMS)?*
2) *What are the necessary Web elements and their ontology structure for WB-NDMS?*
3) *How should one develop such an ontology structure based on available sample data?*
4) *How can such an ontology structure be distributed online for easy navigation?*

An accessible and comprehensive ontology structure developed in this research, called Web-based ontology structure (WB-OS), can potentially assist organizations, managers, and individuals who are involved in disaster management in their WB-NDMS development and evaluation. First, it provides a useful resource to those who are involved in developing WBNDMS.WB-OS covers all phases of natural disaster management and allows easy navigation of the ontology structure at different levels of detail.

## II. BACKGROUND

Across the world, disasters happen frequently. There are various types of disasters, including natural disaster, technological disaster, pandemic disaster [7], and mass violence, where each of which has certain level and type of impacts [8]. Although the impacts of disasters have been extensively investigated, there has been inadequate research on the design of disaster management systems. Furthermore, little attention has been paid to Web-based disaster management and its contributions to the well-being of affected individuals and organizations. More generally, existing research on emergency response information systems is still scant [9], [10].

In this paper, we focus on natural disasters and, specifically, on issues related to the design of Web-based information systems for managing various phases of natural disasters. A natural disaster may be a hurricane, tornado, typhoon, flood, fire, or earthquake. Generally, "a natural disaster occurs when an extreme geological, meteorological, or hydrological event exceeds the ability of a community to cope with that event"[11, p. 176].

In the context of organizational crisis, Pearson and Mitroff[12] suggested that there are five phases in disaster management: signal detection, preparation/prevention, containment/damage limitation, recovery, and learning. Signal detection may be a stand-alone phase in organizational disasters. For natural disasters, however, signal detection and preparation typically take place in the same phase. On the other hand, there is a "general preparation" phase, which is not tied to a particular disaster occurrence but is related to information and public education regarding preparation for natural disasters in general. Similarly,Mileti [13] proposed a model of disaster management with four phases: mitigation, preparedness, response, and recovery.Web elements are critical in developing Web-based systems to deal with various phases of natural disasters.

## III. RESEARCH METHODOLOGY

Following a grounded-theory approach, we identify the Web elements of the WB-NDMS from existing Web sites related to natural disaster management. To handle the complexity of these elements, we develop an ontology [16] with a hierarchical structure using a proposed incremental schema integration (ISI)method and employ selected semi structured data representation approaches to code the ontology structure. An ontology is "an explicit specification of a conceptualization" [17, p. 199]. The main purpose of ontologies is to facilitate knowledge sharing and promote reuse [17], [18]. In an ontology, we define the terms of a domain and identify the relationships among them, thereby formalizing domain knowledge. In this paper, we group and define the Web elements in the WB-NDMS and identify the relationships among them, hence creating an ontology structure for the Web elements.

### *A. GROUNDED-THEORY APPROACH*

To identify the Web elements, we carry out constant comparison and categorization of elements, as prescribed by the grounded theory, which is "the discovery of theory from data"[19, p. 1] and which advocates an iterative, qualitative, and inductive process [20]. The grounded theory was originally developed by Glaser and Strauss in 1967 [19]. Later, Strauss and Corbin [21] proposed a more structured process with three types of coding: open, axial, and selective. Starting with a

Collection of qualitative/textual data, open coding involves an inductive and iterative process of constant comparison and categorization of data, leading to the emergence of unitary abstract

concepts. These concepts are further categorized, and their relationships are established at the axial stage of the coding process, again using constant comparison and categorization. The relationships normally have a hierarchical structure. The selective coding stage involves further abstraction and the development of an emergent theory or the conceptualization of a general structure from the data.

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Following open coding, we compare and contrast data elements (textual Web-element data from Web sites), leading to conceptual Web elements and their categories. The axial coding process structures the categories in hierarchies of relationships. New data elements are introduced iteratively, the analysis is repeated, and the results are modified. The process continues until all of the available data have been consumed or the

TABLE I
BASIC SUMMARY STATISTICS ABOUT THE COLLECTED WEB SITES

| Type | Number of Sites | Average Number of Pages Per Site |
|---|---|---|
| State Sites | 50 | 67 |
| City and County Sites | 37 | 35 |
| Other Governmental Sites | 8 | 130 |
| Non-profit Organization Sites | 3 | 97 |
| Commercial Company Sites | 2 | 29 |

To construct the ontology structure for WB-NDMS, we group the Web elements into five categories that correspond to the five phases of natural disaster management: general preparation, preparation for a given disaster, disaster in progress, disaster recovery, and learning. Within these five main categories, subcategories surface through a constant comparison of Web elements found in various natural disaster management Web sites. We embed the grounded-theory approach within the proposed method for developing the ontology structure (as discussed in the following).

### *B. Selection of Data Representation Approaches*

We adopt a semi structured data representation [22], [23], which helps us constantly identify, compare, and categorize new Web elements following the grounded-theory approach. We select eXtensible Markup Language (XML) [24], XML Schema [25], and Document Object Model (DOM) [26] as the specific modeling approaches. We use XML to represent semi structured data models. A semi structured data model is used to capture the structure of a document instance [27]. *XML* is one of the most popular data models for semistructured data on the Web today [28].

We use XML schema to represent data schemas. A data schema is an abstraction of data models, and it contains constraints, types, and relationships of the data elements. For the semi structured data, the structure is often not fully known in advance and is created after the data become available [29].

### *C. Proposed ISI Method*

Following the axial and selective coding in the grounded theory, we apply a schema integration approach in integrating the semistructured data schemas derived based on different disaster management Web sites. Schema integration is "the activity of integrating the schemas of existing or proposed databases into a global unified schema" [34]. Batini *et al.* [34] proposed a process consisting of four steps: preintegration, comparison of the schemas, conforming the schemas, and merging and restructuring. In the preintegration step, integration processing strategies, including ladder binary, balanced binary, one-shot *n*-ary, and iterative *n*-ary, are evaluated and selected. Binary strategies integrate two schemas at a time, whereas *n*-ary strategies simultaneously integrate multiple schemas at a time. The ladder binary strategy merges a local schema into an existing integrated schema.

***Preintegration:*** This phase synthesizes the ideas of preintegration from Batini *et al.* [34] and schema translation from Ram and Ramesh [35]. All of the Web elements identified from the Web pages are captured as XML elements and are

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described by XML Schemas, which are visualized as tree structures using DOM. The resulting local schema of round $j$ is a tree (denoted as $Lj$ ), whose nodes represent the identified Web elements.

***Schema Matching:*** Naming conflicts and naming matching are checked, marked, and maintained in this phase. The first step of schema matching is to find the corresponding elements from two schemas: the current global schema ($Gj-1$ prior to round $j$) and the local schema ($Lj$) under investigation.Initially, the global schema $G0$ has the root "Natural Disaster Management" and one level with five Web-element categories that correspond to the five phases of natural disaster management. In a subsequent round ($j$), we match the Web elements in the local schema ($Lj$) with those in the global schema ($Gj-1$) using a nested breadth-first search. We consider the Web elements in $Lj$ in a breadth-first manner. For each Web element ($m$) in $Lj$ , we search for a matching Web element in $Gj-1$, also in a breadth-first manner. If the parent or an ancestor of$m$has already been matched to aWeb element $n$ in $Gj-1$, the search for a Web element in $Gj-1$ matching $m$ is restricted to the subtree rooted at $n$. Starting from the root of each schema tree, we mark the matching Web elements.According to the schema matching literature [37], [38], while several semiautomatic matching techniques have been proposed, human intervention is still necessary. We carry out the enumeration of the Web elements manually in this paper.

*D. Ontology Structure Development*

Ontology development is labor intensive and time consuming. There are several techniques for learning ontological knowledge from various forms of data (see [40] for a comprehensive survey), potentially reducing the cost of ontology development and refinement. However, fully automating the ontology development process still remains infeasible, and most learning techniques require some existing top-level ontology or seed concepts [40]. Considering the novelty of our ontology structure development process (this is a first attempt in developing an ontology structure of elements for WB-NDMS) and the lack of an existing natural disaster management dictionary,we choose to adopt a manual procedure and follow a rigorous grounded-theory approach, trading efficiency for higher quality.

Inputs:
The current round, $j$.
The global schema prior to the current round, $G_{j-1}$.
The local schema of the current round, $L_j$.
Schema matching (between $L_j$ and $G_{j-1}$) result stored in $M$, which is a sequence of pairs of references. $M$=($m_1$, $m_2$, …$m_n$). $m_i.L$ and $m_i.G$ refer to "matching" nodes in $L_j$ and $G_{j-1}$, respectively. $M$ is sorted in descending order on the depth (number of levels from the root) of the node referred to by $m_i.L$.
Output:
An updated global schema $G_j$.
Begin
1. $G_j$=$G_{j-1}$.
2. If $M$ is empty,
Insert $L_j$ as a sub-tree into $G_j$ under the node that is the immediate conceptual parent of the root of $L_j$.
Go to the End.
3. For $i$ from 1 to $|M|$,
For each sub-tree $S$ in $L_j$ that is directly below the node referred to by $m_i.L$ (denoted $n$) and does not contain any "matching" node,
Insert the sub tree $S$ into $G_j$ under the node referred to by $m_i.G$.
Mark the nodes in the sub-tree $S$ as "merged".
If all nodes directly below $n$ are marked as "merged",
Mark $n$ as "merged".
4. If the root of $L_j$ is marked as "merged",
Go to the End.
5. For $i$ from 1 to $|M|$ such that the node referred to by $m_i.L$ (denoted $n$) is not marked as "merged",
For each $l$ from 1 to $i$-1such that the node referred to by $m_l.L$ (denoted $m$) is two or more levels below $n$ and none of the nodes between $n$ and $m$ is marked as "merged",
Insert the path between $n$ and $m$ into $G_j$ as a path between the node referred to by $m_i.G$ and the node referred to by $m_l.G$.
Mark the nodes between $n$ and $m$ as "merged".
Mark $n$ as "merged".
6. If the root of $L_j$ is marked as "merged",
Go to the End.
7. Starting from the lowest level and processing upward level by level, for each node $n$ in $L_j$ that is not marked as "merged",
If the root of $L_j$ is not marked as "merged",
Insert the path from the root of $L_j$ to $n$ into $G_j$ under the node that is the immediate conceptual parent of the root of $L_j$.
Else,
Insert the path from the root of $L_j$ (excluding the root) to $n$ into $G_j$ under the node corresponding to the root of $L_j$.
Mark the nodes in the path from the root of $L_j$ to $n$ as "merged".
End.

Fig. 1. Schema-merging procedure.

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Noy and McGuinness [18] suggested a guideline for ontology design with seven steps: 1) determine the domain and scope of the ontology; 2) consider reusing existing ontologies;3) enumerate important terms in the ontology; 4) define the classes and the class hierarchy; 5) define the properties (slots) of classes; 6) define the facets of the slots; and 7) create instances.

The first four steps focus on developing an ontology structure, while the last three elaborate an ontology with properties and instances. We synthesize the first four steps of Noy and McGuinness' [18] guideline, which are relevant to our need, with our proposed ISI method to develop the ontology structure. We categorize the Web elements into five categories, with each corresponding with one of the phases of natural disaster management. Thus, Web elements are grouped according to the categories to which they belong.

Inputs:

The initial ontology structure $G_0$ consisting of five elements corresponding to the five phases of natural disaster management.

An inventory of webpages drawn from WB-NDMS sites.

Output:

An ontology structure for WB-NDMS induced from the sample webpages.

Begin

1. Randomly select a fresh webpage from the inventory of webpages for processing.
2. Identify pieces of information in the webpage as instances of web element.
3. Develop a local schema ($L_j$ in round $j$).
   3.1 Model the identified elements *using* XML.
   3.2. Capture the structure of the XML document using XML Schema.
   3.3. Represent the elements and structure in the DOM graphical model, resulting in a local schema.
4. Using the grounded theory, compare and contrast the elements in $L_j$ with those in the current global schema $G_{j-1}$. Apply the ISI method to create updated global schema $G_j$.
5. Repeat 1-4 until all webpages in the inventory have been consumed or the global schema does not change anymore.

End.

Fig. 2. Ontology structure development procedure.

Fig. 2 shows our overall procedure for ontology structure development. Step 1 selects a new Web page for processing. One may process Web pages either by randomly selecting pages from the inventory of Web sites or by systematically focusing onWeb pages from one site and by completing the site analysis prior to moving to another site. We apply a random sequence, as the grounded-theory approach mandates. Step 2 corresponds with the enumeration of terms and the definition of classes in ontology development. Step 2 also accomplishes the categorization phase of the grounded-theory approach. Step 3 corresponds with the development of class hierarchy in ontology development. Step 4 accomplishes the comparison and further categorization phase of the grounded-theory approach. Finally, step 5 accomplishes the "constant" aspect of the grounded theory approach, which requires continuation of processing and building from additional data and evidence.

## VI. CONCLUSION AND FUTURE RESEARCH

Understanding the necessary Web elements and their ontology structure has critical implications in the development of an effective WB-NDMS. Toward that end, we have attempted to address four relevant research questions. The first research question was on the choice of appropriate approaches for managing the large and complex structure of Web elements needed for creating WB-NDMS. Our review and evaluation of existing semi structured data modeling and schema representation approaches led to the choice of the combination of XML, XML Schema, and DOM. The second research question was related to the identification of Web elements and ontology structure for WB-NDMS. By combining the grounded-theory approach and the selected data representation approaches, we have proposed

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a procedure for this purpose. The third research question was on the method for constructing the ontology structure based on a collection of sample Web pages.

Our developed ontology structure provides a valuable guideline in creating new WB-NDMS Web sites as well as in benchmarking the sufficiency and comprehensiveness of existing Web sites. Our methodology is general, and it can be applied in modeling other complex semi structured domains about which little knowledge is available and in creating guidelines and tools that would assist developers and evaluators of Web sites in such domains.

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