An Approach to Qualitative Emergency Management

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Abstract Emergency Management Systems (EMSs) are playing an important role to save people's life's and to reduce the effects of disasters such as earthquakes or floods. In this paper, we propose an approach to qualitative emergency management. This will empower emergency managers to query spatial databases using qualitative terms used in spoken language, such as 'near' or 'north of'. By providing a qualitative DBMS layer that covers the three qualitative aspects topology, distance, and direction, our system is able to handle qualitative spatial queries. Qualitative spatial queries are translated into formal Structured Query Language (SQL) database queries which are used to query and retrieve results from spatial databases.

Keywords Emergency management system · Volunteered geographic information · Qualitative spatial representations · Matching · Spatial indexing

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S. Zlatanova et al. (eds.), *Intelligent Systems for Crisis Management*, Lecture Notes in Geoinformation and Cartography, DOI: 10.1007/978-3-642-33218-0_4,
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1 Introduction

Every year thousands of people are killed and hundreds of thousands more have to escape their homes due to natural disasters like earthquakes or floods. From 1970 up to 2007, 860,000 people were killed by earthquakes and 535,000 by storms and floods [8]. However, immediately after natural hazards such as the earthquakes in Vientiane/Laos (2011), Tabriz/Iran (2012), and Sulawesi/Indonesia (2012)[1] fast response and recovery capabilities of Emergency Management Systems (EMSs) play a crucial role to save people's lifes. People who are stranded by landslides and partially or totally damaged buildings in the disastrous areas have only a good chance to survive if they are rescued within 72 h—the so-called 'Golden 72 h' [9].

Especially in emergency situations where the scenarios can change rapidly, exact geometric information is often not (yet) available (for example, detailed information about flooded areas). Especially in less developed countries, up-to-date information about emergencies can be impossible to acquire in short time, in particular from remote areas. Thus, we can expect that much of the information is coming from oral reports. Humans rather communicate by means of qualitative terms such as 'near', 'big', or 'away from' than in terms of quantitative values [2]. Hence, a major challenge to EMSs is to allow for coping with qualitative data in geo-spatial databases. In particular, this enables an EMS to offer more natural and intuitive interfaces. Queries and instructions like "Spread goods in areas that are near to Main Street, but far away from damaged buildings and water" should be handled appropriately.

In this paper, we present an approach to integrate qualitative data into an EMS. We claim that emergency managers will benefit from our approach to query geo-spatial databases of EMSs by means of qualitative spatial terms. To handle qualitative spatial data, a qualitative layer that covers the three qualitative aspects, features respectively, topology, distance, and direction needs to be integrated into the DBMS. We show the applicability of our approach by implementing a prototypical system query system that allows for querying qualitative information from a spatial database. Simplified, qualitative queries are translated into formal geospatial SQL queries which are then matched against precomputed qualitative information within the geospatial database. Finally, a list of matches is generated and presented to the emergency manager.

2 A Framework for Qualitative Emergency Management

In this section, we describe the overall architecture of a *Qualitative Emergency Management System* (QEMS), which is illustrated in Fig. 1. Initially, we assume that databases of QEMS contain *n* objects in a vector format which are indexed by

[1] See www.emdat.be for details.

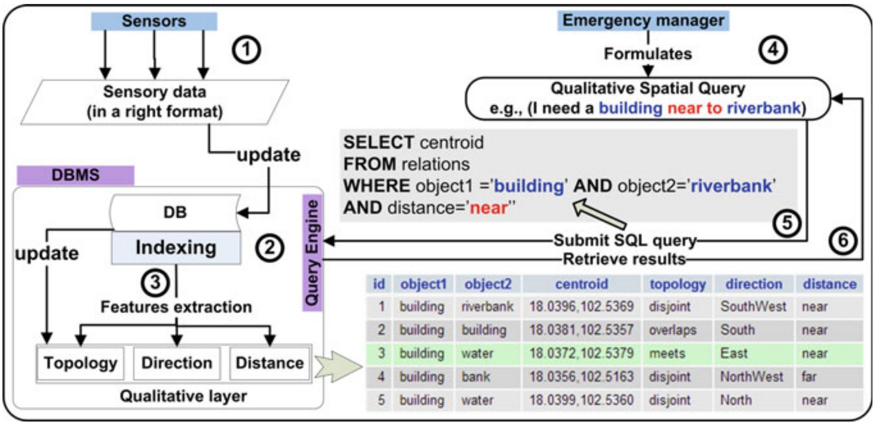

Fig. 1 Architecture of the qualitative emergency management system (QEMS)

an R-Tree [6]. The QEMS indexes and updates new objects (coming from step 1) in the database in step 2. Qualitative spatial information is achieved by abstraction and brought to the qualitative layer of the DBMS in step 3. The querying operation is performed in the remaining steps.

2.1 Indexing

Spatial databases contain a vast amount of objects. In general, answering qualitative spatial queries requires exponential time [14], because all objects and their relations towards each other must be considered to answer a query. Several data structures were proposed to cope with a huge amount of spatial objects [11]. R-tree supports spatial access methods by indexing multi-dimensional data (e.g., polygons or geo coordinates). The key idea of R-trees is to compute the Minimum Bounding Box (MBB) of objects which are then grouped into clusters in the next higher level of the tree where the MBB of all objects contained is calculated. If a spatial query does not intersect the MBB of a cluster then it cannot intersect any of the contained objects in this cluster. However, R-trees provide efficient update, add, and delete operations which allow to update and integrate incoming data (from step 1) into the database.

2.2 Feature Extraction

Geo-spatial databases store the data in quantitative vector format. To enable qualitative usage, all possible qualitative spatial relations in the 2D domain need to be identified [1]. These relations need to be abstracted from the database objects and administrated in a qualitative layer. Currently, our system only deals with binary relations, i.e., relations that hold among pairs of objects. For instance, in a spatial query like 'Find a building near to riverbank', *near* is a binary relation that holds between the objects *building* and *riverbank*. In the context of GISs, Freeman proposed thirteen spatial relations for objects in a 2D scene which are beneficial to develop GISs [5]. Eleven binary relations out of these 13 relations are all covered by the spatial aspects (or features) of topology, distance, and direction. Nevertheless, we neglect relations of type 3D (above) and ternary (between). The abstraction process requires to compute the qualitative relations (per each one of the three qualitative features) between each object (reference objects) and other objects (referenced objects). Given a set of geometric objects $O = \{o_1, \ldots, o_n\}$ stored in DB where o_i contains a set points , the QEMS computes (or abstracts) the qualitative relations of each qualitative feature for each pair of objects (o_i, o_j) in the database, where $i \neq j$.

Topology relations: To abstract topological relations, the 9-intersection model [3] that abstracts 8 topological relations {equal, disjoint, meet, overlap, contains, covers, inside, and coveredBy} is used.

Direction relations: We apply the Cardinal Direction Model [13] for extended objects to abstract direction relations. Based on the minimum bounding box (MBB) of a reference object the space is partitioned into nine regions: (*S*outh, *S*outh*W*est, *W*est, *N*orth*W*est, *N*orth, *N*orth*E*ast, *E*ast, *S*outh*E*ast, and same location *B*). A referenced object (referent) may be completely contained in one of the nine regions. This is called 'single (tile) relation'. However, as the model deals with extended objects a referent may cover more than one region (partially or totally) which leads to 512 'multi-tile' or conjunctive direction relations wrt. a reference object.

Distance relations: Based on the qualitative distance model [7], we propose a distance model that assigns one of the four distance relations *equal*, *near*, *medium*, and *far* to pairs of objects in $\mathbb{R}^2$. Again, this representation is based on the MBB. Let P denote the centroid of the MBB. In addition, $d_{max} = d_3$ denotes the maximum distance between P and one of the corners of the MMB. In order to define the four relations we need two additional distance values d_1 and d_2 with $d_0 < d_1 < d_2 < d_3$. d denotes the distance between the object of interest and P. The relation is considered *equal* iff $d = 0$, *near* iff $d_0 < d \leq d_1$, *medium* iff $d_1 < d \leq d_2$, and *far* iff $d_2 < d \leq d_3$. In Fig. 2 we depict a distance model regarding a fixed region of interest with an equidistant partition scheme regarding all d_i.

The bottom-right area of Fig. 1 shows a snapshot from the qualitative layer as a qualitative spatial relation table. Field 2 (Object1) and field 3 (Object2) represent values for pair of objects (e.g., building as a reference object relates to other referenced objects). The fourth field (centroid) represents the location of the geometric center of objects in the 2D plane by using latitude and longitude coordinates. The remaining fields store three types of qualitative spatial relations that hold between reference objects and other referenced objects. Practically,

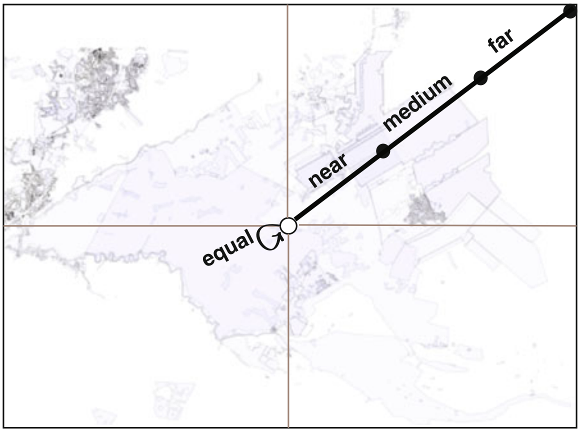

Fig. 2 The distance model with four relations

instead of computing the qualitative spatial relations at run time, they can be precomputed in advance and stored in a database which allows near real-time answers of spatial queries. However, the abstraction process still leads to an explosion of data which needs to be stored in a database. To deal with this problem, reduction techniques are proposed in [4]. By using reduction techniques, some relations can be inferred from others and suggest a reduction that exploits the superimposition of a uniform grid over the spatial dataset to identify a set of inferable relations. Such relations are not stored and are reconstructed at query execution time. When a database is updated (step 2), the DBMS triggers the qualitative layer to recompute the qualitative relations between updated objects and the remaining objects in the database. Hence, the update operation is a time consuming process. We leave this challenging point for future work.

2.3 Querying

To allow for handling qualitative spatial queries formulated by an emergency manager (step 4), these queries are translated into an SQL query (step 5). The structuring operation is done automatically by detecting each pair of an EM query. Then a reference object, a referenced object, and a symbol of the qualitative feature of each pair are assigned to appropriate fields in SQL which are related to fields in database tables (an example of an EM query in SQL is shown in step 5). Via the interface of the DBMS the query is processed (step 5 and 6). Finally, the results are presented to the EM in a graphical user interface. Due to reasons of space we point the interested reader to [14].

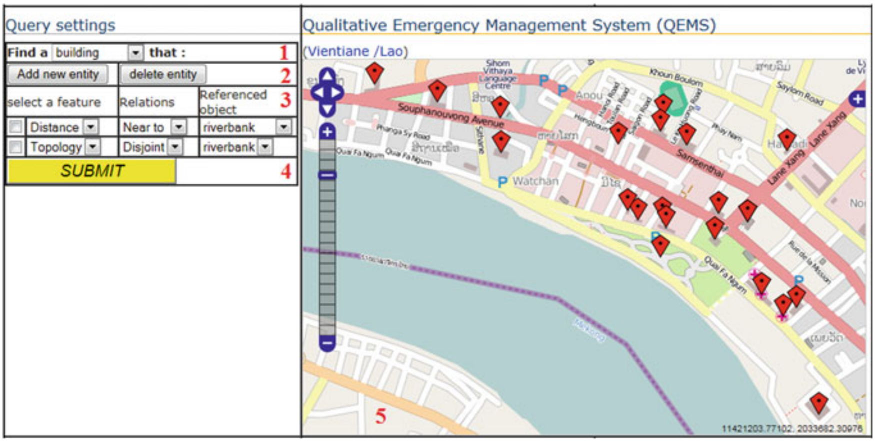

Fig. 3 A snapshot of the graphical user interface of the QEMS, showing the result for the query "buildings near to the riverbank, but not directly at the riverbank"

3 Implementation

Based on the architecture in Fig. 1, we implemented a prototype of an QEMS that enables emergency managers to query interesting places based on qualitative features. We focus on the task to find geo-coordinates of locations that fulfill some specific qualitative spatial features.

A snapshot of the graphical interface of QEMS is shown in Fig. 3. As a testbed we use a geo-referenced dataset of Vientiane (Lao PDR) which was extracted from OpenStreetMap.[2] It contains more than 500 objects. The extracted dataset is stored in a Postgres/PostGIS data-base, rendered by Osmarender and viewed by Open-Layers. However, not all extracted objects are annotated by volunteers, hence a preprocessing step is applied to eliminate non-annotated objects. We marked different spots in the figure from one to five. In the input field denoted by '1', a reference object (e.g., a building) can be selected from a drop-down list. Directly below objects which are supposed to be referenced to the reference object can be added or deleted (field '2'). In connection to this object a qualitative feature (e.g., distance) and a qualitative relation (e.g., "near to") needs to be selected (field '3'). The user of the system does not need to specify any quantitative value for any spatial feature. Figure 3 illustrates that the output of such queries could be helpful for EMs. As an example, it shows the answer to a query for buildings that are near to the riverbank, but disjoined from it (not directly at the riverbank) Emergency managers can formulate such queries to find coordinates of buildings which may, for example help rescue teams to spread goods in right places quickly. From this, an according query is generated (field '4'). Based on this query the QEMS

[2] www.openstreetmap.org

retrieves a set of matches which are displayed (as red markers) on a map (field ‘5’). Red markers denote the result: a set of matches that satisfy the spatial constraints that hold among pairs of objects in the EM query.

4 Related work

Recently, several systems and methods have been developed to response to natural disasters. Google Crisis Response[3] is a platform for empowering people to contribute to the status of disastrous areas (e.g., people can send test messages via mobile phones). Based on this data a spatio-temporal database of events is created, which can be queried by emergency managers.

A system that deals with natural hazards during the phase of disaster responding is presented in [10]. The authors propose a new spatio-temporal indexing method to speed up the query process. However, qualitative aspects are not tackled in this work.

A framework that detects damaged buildings in high resolution satellite imagery is proposed in [12]. The authors use clustering-based techniques to detect damaged buildings by comparing the roof texture of buildings in satellite imagery before and after the actual disaster. The focus of this work was not on querying databases. Other systems and researches were proposed to deal with response and recovery phases of emergency management. However, they mainly do not concentrate on extending DBMSs to handle qualitative spatial queries.

5 Conclusions

Handling qualitative data as coming from natural language is a crucial aspect of Emergency Management Systems. We proposed the integration of a qualitative layer into an EMS that covers topology, distance, and direction. In a prototypical implementation we presented a query system that translates qualitative statements to formal SQL queries and matches them to precomputed relations between objects in the spatial database. Thus, it is possible to answer qualitative queries by presenting a set of matches to the emergency manager for further inspection. This shows the general feasibility of our approach for extending EMSs with the ability to handle qualitative information.

Acknowledgments Funding by the German Research Association (DFG), SFB/TR 8 Spatial Cognition, and by the European Commission Initial Training Network geocrowd (FP7 - People Marie Curie Actions) is gratefully acknowledged.

[3] http://www.google.org/crisisresponse

References

1. A. Cohn, J. Renz, *Qualitative Spatial Representation and Reasoning, Handbook of Knowledge Representation* ed. by F. Harmelen, V. Lifschitz and B. Porter (Elsevier, 2007), pp. 551–596
2. M.J. Egenhofer, Query processing in spatial-query-by-sketch. J. Vis. Lang. Comput. **8**(4), 403–424 (1997)
3. M.J. Egenhofer, R.D. Franzosa, On the equivalence of topological relations. Int. J. Geogr. Inf. Syst. **9**(2), 133–152 (1995)
4. P. Fogliaroni, G. De Felice, F. Schmid, J.O. Wallgrün, Managing qualitative spatial information to support Query-By-Sketch, in *Understanding and Processing Sketch Maps (COSIT'11)*, vol 42 (IOS Press, Amsterdam, 2011), pp. 21–32
5. J. Freeman, The modelling of spatial relations. Comput. Graph. Image Proc. **4**, 156–171 (1975)
6. A. Guttman, R-Trees: A Dynamic Index Structure for Spatial Searching. SIGMOD Conference,47–57 (1984)
7. D. Hernández, E. Clementini, P. Di Felice, Qualitative distances, in *COSIT'95* (Springer, Berlin, 1995), pp. 45–57
8. K.D. Hurley, Planning and mitigation for emergency situations and natural disasters in hennepin county, minnesota utilizing GIS, in *Resource Analysis* (Saint Mary"s University of Minnesota Central Services Press, Winona, 2009)
9. H.C. Jang, Y.N. Lien, T.C. Tsai, Rescue information system for earthquake disasters based on manet emergency communication platform, in *Proceedings of the 2009 International Conference on Wireless Communications and Mobile Computing: Connecting the World Wirelessly*, IWCMC'09 (ACM, New York, 2009), pp. 623–627
10. R. Laurini, S. Servigne, G. Noel, Soft Real-Time GIS for Disaster Monitoring, ed. by P. Oosterom, S. Zlatanova, E.M. Fendel, in *GI4DM*, (Springer Berlin , 2005), pp. 465–479
11. Y. Manolopoulos, Y. Theodoridis, V.J. Tsotras, Spatial indexing techniques, in *Encyclopedia of Database Systems* ed. by L. Liu, M.T. Zsu, (Springer, New york, 2009), pp. 2702–2707
12. F. Samadzadegan, H. Rastiveisi, A clustering-based technique for automatic damage map generation using high resolution satellite imagery, in *Gi4DM*, Antalya, Turkey, 2011
13. S. Skiadopoulos, M. Koubarakis, Composing cardinal direction relations. Artif. Intell. **152**(2), 143–171 (2004)
14. J.O. Wallgrün, D. Wolter, K.-F. Richter, Qualitative matching of spatial information. in *Proceedings of the 18th SIGSPATIAL International Conference on Advances in Geographic Information Systems, GIS'10* (ACM, New York, 2010), pp. 300–309