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An object-relational prototype of GIS-based disaster database

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Abstract

Global natural disasters have caused billions of dollars of property and infrastructure damages, unexpected disruption to socioeconomic activities and tragic loss of human lives each year. It is of paramount importance to collect, maintain and manage detailed and accurate records of disastrous events for an effective risk assessment and mitigation of disaster impacts. Considerable efforts have been directed towards the establishment of databases on historic disasters but many disaster databases built are primarily a set of separate lists of historical disaster events. This paper presents a recent study that investigates effective and efficient GIS-based approaches to the representation, organisation and access of disaster information. This includes logical data models for representing disastrous events, the object-relational approach to database implementation, and internet-based user-interfaces that supports multi-mode (including map-based) database queries and flexible facilities for report generation. Key aspects of a disaster event, including the spatial-temporal dimensions of the hazard and its impacts, are considered in the development of data models and database implementation in order to support user-friendly querying and reporting operations.

Keyword: disaster event; object-relational data model; geographical information system; impact and risk assessment

1. Introduction

It is well known that natural disasters have caused significant economic, social, financial, property and infrastructure damages and even tragic loss of human lives each year. Recent devastating events, such as the Indian Ocean tsunami and the American hurricanes in 2005, have made us all acutely aware of the great impacts of natural disasters [1]. In Australia, the damage of natural disasters is more than $1.14 billion each year [2].

To reduce disaster impacts and achieve safer, more sustainable communities, the importance of proper understanding and management of disaster events has been widely recognised [3]. Information on natural disasters can be better acquired, interpreted, and disseminated by using the latest information and geospatial technologies. Much benefit can be achieved in terms of disaster management and control, from preparedness, prevention, and protection through detection to response and eventual recovery [4].

In the past decade, considerable research effort has been directed towards the establishment of databases on historic disasters. As a result, many disaster databases have been built. However, most of these databases are

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primarily a set of independent lists of disaster events with very limited support for map-based querying and reporting operations [5]. Databases of disasters should be an integral part of the important knowledge base on the level of hazard, vulnerability, disaster impacts and disaster scenarios.

Disaster phenomena vary dramatically with both space and time and their spatial and temporal aspects must be integrated into the disaster information management systems [4]. Hence, for the impacts assessment and emergency response of disaster events, both spatial and temporal aspects should be represented, and the capability of efficient and interactive temporal-, spatial- and attribute-oriented queries should be incorporated into a disaster database [5]. It is therefore important to integrate spatial-temporal dimensions of disaster events in a disaster database and make such a database readily accessible by a variety of users (from government agencies, non-government organizations, research institutes and local communities).

This paper presents our preliminary study of a GIS-based approach to the representation, organization and access of disaster information - including logical data models for representing disastrous events, the object-relational approach to database implementation, and internet-based user-interfaces for database queries and report generation. Key aspects of a disaster event, including the spatio-temporal dimensions of the hazard and its impacts, need to be considered in the development of data models and database implementation in order to support user-friendly querying and reporting operations. The technological strengths of Geographical Information System (GIS) (e.g. ArcGIS), Database Management System (DBMS, e.g. ArcSDE and Oracle Spatial), and Internet-related toolbox (e.g. ArcGIS Server) need to be leveraged for developing a prototype of a GIS-based, object-relational disaster database with an internet-based user interface that supports multi-mode (including map-based) database queries and flexible facilities for report generation.

2. The guiding principle

![Fig. 1. Guiding principles of disaster database enhancement](image)

To achieve cost-effective, evidence-based disaster impact reduction, the knowledge base should be constructed in such a manner that the dynamic and complex relationships, connections, and interactions between the damaging
hazards, vulnerable communities and actual disaster impacts are faithfully established, and hence questions of what, who, when and where in risk analysis and emergency management are answered efficiently and effectively. A guiding principle for Disaster Database Enhancement (illustrated in Figure 1) has been developed in earlier studies by the authors [5].

3. The case study

Flooding is one of the most damaging disasters in Australia, with annual losses more than $300 million in recent years [5]. This research investigates in the disasters spatio-temporal representation, data modelling, and data accessing and reporting by using flooding events happened in the Gardiners Creek catchment (Figure 2) in Australia as a case study.

3.1. The study area

Yarra River in Victoria is the major river running through the City of Melbourne, and Gardiner Creek is one of the principal tributaries of the Yarra River which drains the inner south-eastern suburbs of Melbourne. This predominant urban catchment consists of Gardiners Creek, Scotchmans and Damper creeks, and the total area of Gardiner Creek catchment is approximately 115 km$^2$, which covers 44 localities in 6 local government areas (LGA) and the population density in this area is about 2,300 persons/km$^2$ [6].

3.2. Historical datasets

Major flooding events happened in Gardiners Creek Catchment in recent 10 years (year 1995-2005) are used as primary inputs in this case study. Information on these events includes the time period of the event, the water overflow areas, the flood area boundary and other spatial information.

Apart from flooding data, other spatial datasets are also needed to represent the physical world that is damaged or affected by the disastrous flooding events. These spatial datasets include Digital Elevation Model (DEM), administration boundaries, hydrographical features, properties, infrastructures, utilities, etc.
4. The methodology and preliminary results

4.1. Data Model

A data model is a logical organisation of the real-world objects (entities), constraints on them and relationships among objects, which helps to simplify and abstract a more complex real-world object or event [7]. A data model describes all the data entities in the domain of interest including how the data is represented and accessed, the data structure and their characteristics, constrains, transformations and the interrelationship among the data elements. A well-developed data model can facilitate the data storage, management and usage, as well as foster improved understanding of the selected real-world object or event [8]. The recent trend of development is to apply object-oriented technology in spatial database management system. Comparing with traditional data model such as map file-based model and relational model, object-oriented data model is representation of a number of object classes (i.e. flood events, properties and land), which are much more advanced in encapsulation and extensibility.

To represent the complex natural disaster events, the data model should contain information of the disaster event, including spatial, temporal, attribute data, and information on damages and losses caused by the disastrous events, information on geographical elements that affected by or related to disaster events, as well as information on representing of the context of disaster events such administrative areas [9].

4.2. Database schema

Base on the data model, a logical database schema is designed in this study, and an object-relational DBMS is implemented according to the logical database schema.

The schema of a database system defines the structure of the DBMS. In a relational database, the schema defines the tables, the fields in each table, and the relationships between fields and tables. The proposed implementation uses the object-relational features of the Oracle DBMS, including the possibility of declaring object types with associated methods, aggregation structure of nested tables, and the implementation of object referencing with an attribute of object reference data type. It is anticipated that these paradigms will simplify logical models of the database. Figure 3 shows the key schemas used in the database design. Each schema has a number of objects that represent the objects related to the flooding events. The objects have spatial and temporal attributes and other attributes needed for flooding management i.e. property values and water levels. Methods and behaviours are also defined in each object. Objects act or interact in the processes of the flooding events.
4.3. Internet-based user interface/tools

Nowadays Internet is the most common and popular tool for people to publish and acquire information. With friendly user interface and querying and reporting operations, a web based GIS system can serve and access information on natural disasters in a much more distributed manner.

A map can deliver indispensable information on natural disasters, including location, area, extent and other visual information. ArcGIS Server provides web-oriented spatial data services and supports rich browser-based web mapping application. In this study, ArcGIS Server with .NET framework will be used to create a web-based user interface and provide the spatial data service.

With interactive map interface, query and reporting tools, user will able to carry out different searching and reporting operations. As shown in Figure 4, a spatial query is conducted to display all the properties affected by certain flooding event. User can visually see the affected properties on the map and also generate a report of this searching result.

![Fig. 4. Properties within the extent of 100-year flood](image)

![Fig. 5. An overview of a three-tier system architecture proposed in this research](image)
4.4. An overall flowchart/diagram of the methodology

The three-tier system configuration is regarded as very suitable for large data volume database implementation [10], and for supporting efficient ad hoc data processing, manipulation and analysis [11]. Hence, a three-tier architecture consisting of presentation, business logic and data/resources is implemented in the proposed system. Figure 5 provides an overview of the system architecture.

The presentation tier that is the front-end interface for users to interact with the system runs as client on users’ desktop PCs. Business logic that is for validation and process functions runs on a middle-tier application server. In this proposed system, this tier consists of web server and application server. Web server will cope with the presentation tier and transfer user requests to application server, and then application server will implement the business logic and transfer the interpreted requests to next tier – data tier. Data tier runs on a data server, which consists of database management system (DBMS) that stores all the datasets and database server that manages the data access to the database. Database server will retrieve the information requested from the database and return the results.

According to the architecture design outlined above, the system will be developed on a platform consisting of Oracle 10g, ArcSDE, ArcGIS Server, Apache and Tomcat. Oracle 10g provides efficient, reliable, secure data management for high volume online transaction processing environments, query-intensive data warehouses, and demanding Internet applications. With spatial component, it is also capable of effective spatial data management. Therefore, Oracle 10g is selected as a DBMS in this study. ArcSDE can be phased in as a spatial data access server that allows for administering spatial data stored in a relational DBMS and provides access to data required for client applications such as ArcGIS Desktop, ArcIMS, ArcGIS Server, and custom applications. With capabilities for supporting concurrent multiuser editing and critical GIS data management work flows, it will be installed and used as a data server in the proposed system. ArcGIS Server provides a great interactive tool for viewing, querying, and exchanging spatial information. It is designed for effective spatial information sharing via the Internet, which provides different viewers for client side presentation, and supports spatial data handling with functions such as feature, query, Geocode, Extract and Metadata. Hence, ArcGIS Server is employed as the application server in the system. Apache is a well-known web server, and Tomcat is a widely used web servlet engine. In this system, Apache will be installed and configured with Tomcat to operate as the web server.

5. Discussions and conclusions

This paper described a prototype web-based GIS system as a tool and a platform to facilitate natural disaster information management, including disaster data organisation, information sharing and publishing, and information accessing, querying and reporting. This includes logical data models for representing disastrous events, the object-relational approach to database implementation, and internet-based user-interfaces that supports multi-mode (including map-based) database queries and flexible facilities for report generation. Key aspects of a disaster event, including the spatial-temporal dimensions of the hazard and its impacts, are considered in the development of data models and database implementation in order to support user-friendly querying and reporting operations.

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