Integrating Qualitative Representation and Reasoning with GIS

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Abstract: Extending GIS with qualitative models of manipulation has been an area of research interest for many years. While much research has already been undertaken to develop qualitative reasoning methods, practical realisation for their integration with GIS is rather limited. The case for qualitative GIS is evident in many applications, including that of mixed-method in the field of social geography. In this paper, approaches to integrating qualitative reasoning and GIS are reviewed and an overview is given of the needs of mixed-method research. Requirements for a qualitative GIS are drawn and a proposed framework to address those requirements is outlined. This work is part of a project that aims to demonstrate the value for integrating both qualitative and quantitative spatial reasoning.

KEYWORDS: Qualitative Spatial Reasoning, Mixed Method Research, Qualitative GIS

1. Introduction

Place names and qualitative spatial relationships are more cognitively available to users than geographic coordinates of place location, and thus are more commonly used by users when describing place information. Extending GIS with qualitative models of manipulation has been an area of research interest for many years and many works have addressed the problems of qualitative spatial representation and reasoning (Cohn and Renz 2001), representation of fuzzy spatial knowledge (Dixon 2005) and understanding spatial language (Shariff et al. 1998).

The case for Naiive geography (Egenhofer and Mark 1995) has strongly emerged over the recent few years, with the proliferation of the geographic referencing (geo-tagging) on the Web. Maps are used as place holders for personal data, resources and for communication and search on the Web. However, the types of geographic analysis and retrieval functions available to users are very limited compared to what is offered in a traditional GIS. This is in part due the nature of geographic data and manipulation expected by users, where data on geographic places may be incomplete, with fuzzy or inaccurate representation of location and may also contain errors. Representation and manipulation of this sort of information is not handled by current GIS.

Mixed-method research has also recently emerged advocating the case for qualitative GIS (Winchester 2005) in the domain of social geography. There, the integration of qualitative research and GIS analysis functions is needed for the study and interpretation of qualitative geographic data, presented in the form of surveys, interviews and observations. Again, the representation and manipulation of this sort of information is not handled by current GIS.

In this work, we propose to extend GIS to support qualitative representation and manipulation of geographic information and thus provide a platform for the seamless integration of new types of applications that would otherwise require proprietary solutions. In this paper, a review of the approaches to integrating GIS with qualitative spatial reasoning methods is presented and an overview of requirements of mixed-methods research is also given. General requirements for the envisaged integrated framework are drawn and an outline of the proposed framework is presented.

2. Related Work

In this section we review approaches to integrating qualitative spatial reasoning with GIS and discuss a particular use case for supporting the need for enabling GIS with qualitative data management; that of mixed-method research in geography.

2.1 Qualitative Spatial Reasoning and Representation (QSR)

A large body of research has been undertaken in the past decade in the field of qualitative spatial reasoning (QSR) with the aim of deriving compositions of spatial relations between different objects in space. Several works studied the representation of different types of spatial relationships and complete and sound sets of relationships have been reported for different types of simple geometric shapes. Cohn and Renz (2001) provide a detailed survey of the field.

Widely accepted formalisms for qualitative spatial representation include a mathematical approach based on the 9-intersection model (Egenhofer et al. 1994) and logic-based approach, stemming from parallel research efforts in the AI community, resulting in the Region Connection Calculus (RCC). In practice RCC and the 9-intersection model produce an identical set of 8 (jointly exhaustive and pair wise disjoint JEPD) relations between two regions, albeit using different relationship terminology. Of the two models, the 9-intersection has a more intuitive and commonly used terminology that is adopted in GIS and spatial databases (Vretanos 2005). Approaches to the representation of other types of qualitative spatial relations, namely, size, proximity and directional relationships, have also been pursued (Skiadopoulos and Sarkas 2007).

Approaches to integrating QSR with GIS initiated primarily from the logic-based camp, where a layered/hybrid approach was proposed to link spatial logic reasoners and GIS. The hypothesis being, that maintaining the separation between the qualitative reasoning engine and the geometric data store is necessary for a scalable solution. Hence, the spatial logic engine would resort to the GIS when it fails to perform the required spatial analysis or computation.

This approach was adopted by Wessel (2003) in a proposal for a deductive GIS based on Description Logic (DL). Three system components (or substrates) are proposed, namely, a spatial database or map substrate, a DL component to model and reason over thematic aspects of the geographic information and a query component where a limited form of qualitative spatial reasoning was envisaged. In particular, an RCC substrate is introduced to support checking the consistency of the spatial relations in the query component. nRQL (Haarslev et al. 2004); a query language for the RacerPro system was used to implement the query component in this framework. A similar approach was proposed in (Stocker and Evren 2009), where a separate RCC engine used for qualitative reasoning was implemented on top of the DL reasoner Pellet.

The idea of incorporating a logic-based engine with a GIS has also been investigated in the KES-B project at ESRIN (Varas et al. 2004), whose aim was to study the use of semantic web technologies for water quality and maritime security applications where complex geospatial queries relating geometries and attributes needed to be supported. A spatial reasoning engine is provided within the architecture to define spatial and thematic (non-spatial) queries between features. A rule-based expert system, integrated with a GIS feature server, is used for resolving the queries. Spatial reasoning in this work was limited to query definition and query expansion.

The approaches above assume the need to extend DL with spatial logics for QSR and loose coupling of the resulting engine with a GIS. The role of the GIS is limited to evaluating geometric computations that are not handled by the reasoning engines. The scalability and application of such approaches have been limited by several factors, including the complexity of extending existing DL and the limitations of current logic reasoning engines to handle large amounts of data typically manipulated in a GIS. In this work, we take the opposite stance to put the emphasis on the GIS and explore methods of tight integration with QSR. To our knowledge this methodology has not been attempted before.

2.2 Mixed-Method Research

Qualitative research attempts to perceive and explicate people's experience in socio-spatial trajectories (Winchester 2005). Recently, the need for mixing qualitative data, resulting from qualitative research methods, and GIS emerged to allow for the triangulation and interpretation of this data (Kwan and Ding 2008).

Jung and Elwood (2010) identify three main methods to integrate qualitative, quantitative and geo-visual approaches in GIS. The first method is based on the transforming of qualitative data and identifying their spatial content to allow for their visualization in a GIS. An example of this approach is in the work of (Kwan and Lee 2004) to visualise qualitative data collected in activity diaries using time and space trajectories. The limitation of this approach is in the alteration of the original qualitative data itself and significant details may be lost while using only those portions of data that can be spatially represented.

The second approach relies on hyperlinking associated artefacts (such as text or sound) with geographic entities in a GIS (Cieri 2003). Qualitative data are stored outside the spatial database as digital files (Jung and Elwood 2010). The third approach aims to harness the strength of both qualitative research techniques, for example, grounded theory, and GIS through linking both systems (Kwan 2008). An example of such system is the Computer-Assisted Qualitative Data Analysis Software (CAQDAS) that provides tools to facilitate the management and analysis of qualitative data. In (Jung 2009) a system is proposed, CAQ-GIS, where both CAQDAS and GIS are used to explore, code, and analyse data simultaneously. The data model in the GIS was modified to enable the storage of qualitative data and interpretive codes. A separate layer, denoted the 'Imagined Grid', was created in GIS to store the data for visualization purposes and to enable its geo-referencing. A “Hybrid relational database” to link the qualitative data and codes with GIS is shown in Figure1.

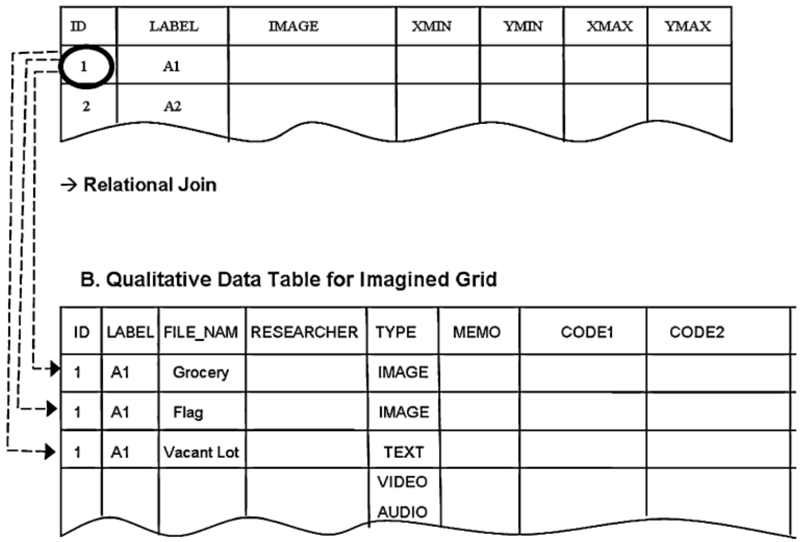

Figure 1. Hybrid relational database linking GIS with qualitative data (Jung and Elwood 2010).

Jung and Elwood (2010) admit the redundancy involved in coding data and storing them in two systems which may create problems in maintaining their consistency. In addition, it might be necessary in any long-term qualitative research effort to revisit and re-code specific data, as new ideas or patterns emerge.

3. A Framework for Developing Qualitative GIS

Previous approaches to integrating qualitative data representation and manipulation in GIS are limited and the need still exists for an integrated platform that supports both types of spatial reasoning offered by QSR and GIS. Approaches to integration of both types of system offered a loose integration between a QSR engine and GIS to allow calls to spatial analysis functions that cannot be processed from the spatial logic reasoning engine. Similarly, approaches to integrating qualitative research with GIS offered a hybrid approach for linking both systems to allow for the projection of the qualitative data in the GIS. The hybrid approach to integration in both cases was shown to be restrictive, mainly due to the dichotomy of representation of qualitative and quantitative spatial data, and the consequent split in manipulation, analysis and reasoning. An approach to address these limitations should therefore consider the following issues.

1. Represent geographic data and spatial relationships in a qualitative manner using established qualitative spatial representation formalisms.
2. Homogeneous integration of qualitative representations and geometric representations of geographic information.
3. Utilise and apply established spatial reasoning techniques for the manipulation of geographic information.

4. Integrate qualitative spatial reasoning methods with GIS spatial analysis methods to support the mixed manipulation of both types of qualitative and quantitative representation in the same system.
5. Support for the qualitative expression of geographic queries and the visualisation of query results.

A framework is proposed that aims to extend a GIS to address the above issues. The framework is shown in Figure 2. A qualitative layer of representation is built on top the underlying topological data structures of a GIS, and which acts as a base for the application of a qualitative spatial reasoning engine. The reasoning engine will communicate with the GIS spatial computation engine to process queries. A query processor orchestrates the communication between the two reasoning engines.

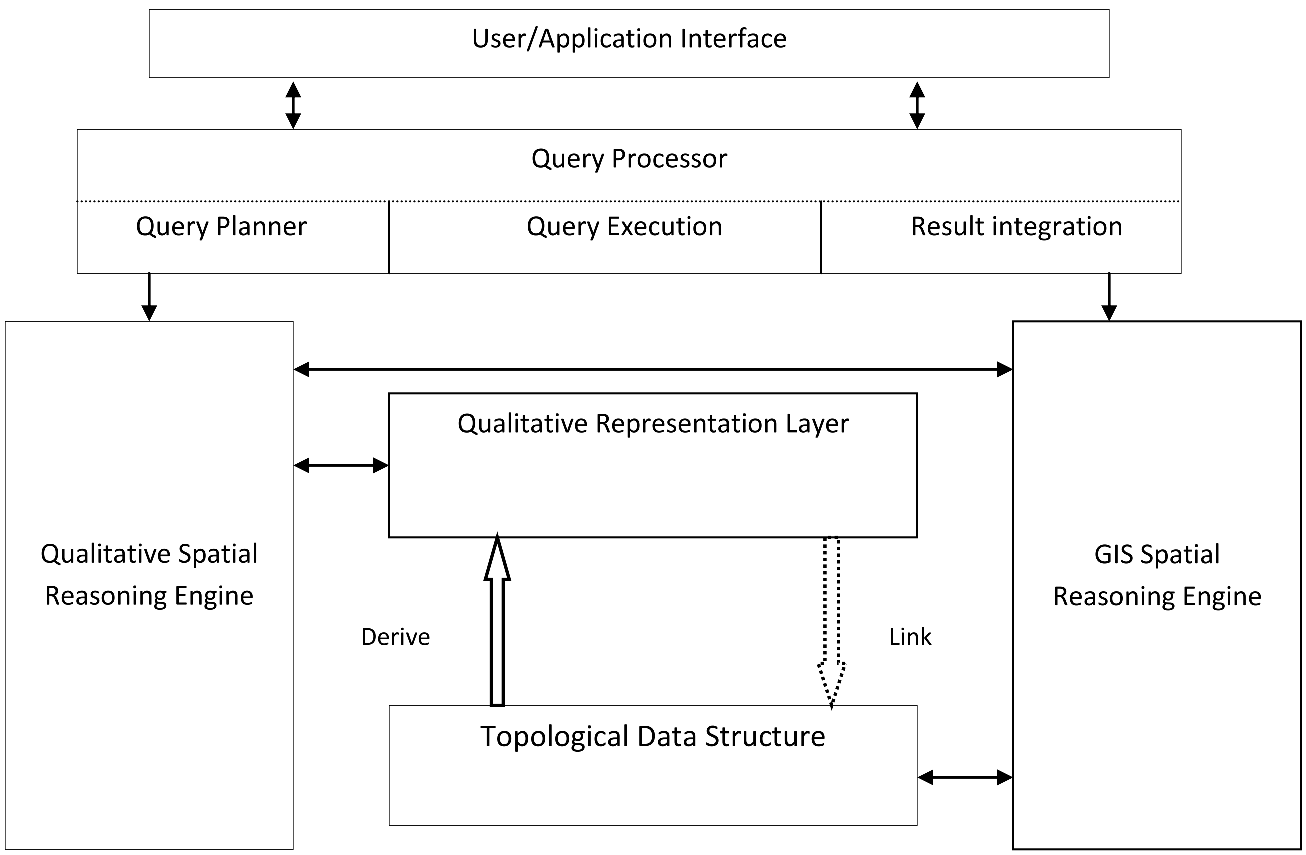

Figure 2. A framework for qualitative GIS.

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Biographies

Khalid Almuzaini is a PhD student at School of Computer Science, Cardiff University. He has an academic and professional background in Geographical Information System. His PhD is focused on the integration of quantitative and qualitative spatial data in an extended model of Geographical Information System.

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