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SCIENCE DIRECT®
Computers, Environment and Urban Systems
xxx (2005) xxx–xxx
Computers, Environment and Urban Systems
www.elsevier.com/locate/compenvurbsys

Spatial queries with qualitative locations in spatial information systems

Xiaobai Yao [a,*], Jean-Claude Thill [b]

[a] *Department of Geography, University of Georgia, Room 204 GG Building, Athens, GA 30605, USA*
[b] *Department of Geography, University at Buffalo, The State University of New York, Amherst, NY 14261, USA*

Abstract

We discuss locations as defined by their qualitative spatial relations to other features, dubbed qualitative locations (QL). We further propose a mechanism to handle queries with qualitative locations in geospatial information systems. For the realization of the mechanism for QL-based queries, we propose a conceptual framework that takes advantage of models of qualitative spatial reasoning to bridge the gap between conventional metric spatial information systems and the general public's common-sense query of spatial relations in natural language.

Keywords: Qualitative spatial query; Qualitative location; GIS; Spatial relations; Qualitative spatial reasoning

1. Introduction

Spatial relations play a central role in Geographic Information Science research. The importance of spatial relations has been recognized in several domains of inquiry including spatial reasoning, spatial data structures, vision, mental and computational

* Corresponding author. Fax: +1 706 542 2388.
E-mail addresses: xyao@uga.edu (X. Yao), jcthill@buffalo.edu (J.-C. Thill).

0198-9715/$ - see front matter © 2004 Published by Elsevier Ltd.
doi:10.1016/j.compenvurbsys.2004.08.001

imagery, cognitive maps and related structures, and knowledge representation (Papadias & Kavouras, 1994). Commonly used spatial relations include *topological relations* that describe neighborhood and incidence, *direction relations* that describe angular order (e.g., North, South), *distance relations* such as "near" and "far", and others. Spatial relations of certain types are modeled by quantitative measurements or are represented qualitatively, depending on the level of specification provided in the proposition. For instance, the distance relation lends itself to a representation by a cardinal measurement such as the Euclidean distance, or by a qualitative description such as "near" or "far". Current geographic information systems (GIS) incorporate powerful tools to handle *quantitative* spatial relations, but their capabilities in reasoning about *qualitative* spatial relations remain very limited, at best. The persistent shortcoming in handling qualitative spatial relations unnecessarily precludes GIS from becoming ubiquitous in managing the multitude of geospatial applications that permeates our contemporary information-oriented society. It is against this backdrop that this paper proposes the new concept of *qualitative locations* (QL) and presents a solution to QL-based queries so as to enable qualitative spatial relations in tasks involving information query, retrieval, or even data entry in geospatial information systems.

The past decade has witnessed a growing stream of research on various aspects of qualitative spatial relations (for example, Frank, 1992, 1996; Freska, 1992; Gahegan, 1995; Papadias, Karacapilidis, & Arkoumanis, 1999; Shariff, Egenhofer, & Mark, 1998). Gould (1989) argued that developing the capability of handling natural language descriptions in general was an important research area to improve GIS user interfaces. More significantly, however, the relevance of research on qualitative spatial relations is embedded in many new enabling geospatial information technologies and in the notion of Naïve Geography, which addresses the issue of accommodating common-sense geographic queries of the general public. Various kinds of geospatial information technologies that have recently come to life extend the public's ability to quickly and easily access geo-referenced information beyond the confines of desktop GIS. The World Wide Web, wireless communication and information technologies, and telematics technologies represent the new face of geospatial applications. Through space-aware devices, location-based services promise to offer users a profusion of information on their local environment in the field or on the street, which in turn enables them to answer all sorts of space-related questions in their daily life.

To keep pace with these new application demands, the old paradigms of relevance to desktop GISs have to be retooled (Egenhofer & Kuhn, 1998). A particular challenge for the design of spatial information systems of the next generation is to equip GISs to handle common-sense geographic queries made by users without specific training in spatial technologies. Because the view of the geographic world held by the general public is in the form of mental images or narrative descriptions, rather than in a digital form as stored in computer databases, people often perceive spatial relations through qualitative descriptions instead of metric measurements. Therefore, it is much more practical for them to formulate spatial queries using qualitative terms. Along this line, Egenhofer and Mark (1995) proposed a research agenda called *Naïve Geography* to accommodate non-expert geographical views espoused by the general public, thus empowering people's cognition of their surrounding geographic environment. Naïve Geography has been defined by Egenhofer and Mark (1995) as "the field of study that is concerned with formal models of the common-sense geographic world... It aims to underpin the design of GISs that can be used without major training by new user communities such as average citizens, to solve day-to-day tasks. It is also the basis for the design of intelligent GISs that will act and respond as a person would, therefore, empowering people to utilize GISs... without stunning surprises when using a system" (p. 1). The National Center for Geographic Information and Analysis subsequently set a research initiative for the development of formal models of the common-sense geographic world (Mark, Egenhofer, & Hornsby, 1997). The conceptual framework of Naïve Geography provides good theoretical ground and justification for the ideas advanced in this paper.

In response to the demand for handling qualitative spatial terms and queries in geospatial information systems of the next generation, this paper introduces the concept of qualitative locations (QL) and proposes solutions for handling queries with QL. We present an integrated conceptual framework for the queries with qualitative spatial relations, in which the qualitative-quantitative translation engine is rooted in an expandable library of qualitative spatial reasoning models. By interactively matching qualitative statements to a geographic frame of reference that is quantitatively defined, and vice versa, the proposed framework demonstrates the capability suited to the task of qualitative spatial data entry and querying. It is our contention that, while some existing models of qualitative spatial reasoning satisfy the qualitative-quantitative translation requirements of handling qualitative spatial query, many new models will be needed before full-featured qualitative spatial queries capabilities can be implemented in commercial spatial information systems.

The paper starts in Section 2 with a review of current spatial reasoning models for qualitative spatial relations. Section 3 introduces the new concept of qualitative locations, discusses the importance of handling qualitative spatial queries with QL, and presents a conceptual framework suitable for its realization in spatial information systems. Section 4 presents a case study and a partial prototype implementation of the conceptual framework. Conclusions and research issues stemming from the proposed concept and approach are discussed in Section 5.

2. Qualitative spatial relations and qualitative spatial reasoning

Following Pullar and Egenhofer (1988), spatial relations commonly used on spatial information systems can be classified into the following five groups: *topological relations* that describe neighborhood and incidence, *direction relations* that describe angular order (e.g., North, South), *distance relations* such as "near" and "far", *comparative or ordinal relations* that describe inclusion or preference (e.g., "in", "at"), and *fuzzy relations* such as "next to" and "close". Because the instances of the latter two types of spatial relations can be subsumed by one or more of the first three, we will discuss these three types of spatial relations only in this paper.

Research on the formalization of topological relations started with the point-set topology (Egenhofer & Franzosa, 1991; Guting, 1988). Along this line, the family of intersection models proposed by Egenhofer and Franzosa (1991) is most influential in spatial information systems. Particularly, the 9-intersection framework provides a formal presentation of topological relations for many subsequent research efforts (Chen, Li, Li, & Gold, 2001; Papadias et al., 1999; Shariff et al., 1998). Other topological models have also been suggested in literature. A notable case is based on region connection calculus (RCC) (Cohn, Bennett, Gooday, & Gotts, 1997; Randell, Cui, & Cohn, 1992). In spatial formalism, the RCC approach takes regions of space as primitive and abandons the traditional point-based geometry. It defines and reasons about topological relations on regions of space. One advantage of the RCC theory is that it can easily be extended to represent regions with uncertain boundaries (Cohn & Gotts, 1996), and therefore it has the potential to model the spatial relations among entities/regions with uncertain boundaries.

Three broad approaches have been proposed to handle inference rules of qualitative reasoning with cardinal directions. In the centroid-based approach, the direction between two objects is determined by the angle between the two object-to-centroid lines (Frank, 1996; Papadias et al., 1999). The second approach relies on the projection-based directions with neutral zone (Frank, 1996). The third approach (Papadias et al., 1999) builds on the centroid-based approach by extending the range of the angles for each cardinal direction with fuzzy membership functions.

Proximity is the distance spatial relation expressed in natural languages. It is also referred to as qualitative distance or linguistic distance. Since the early 1990s, efforts to formalize the mapping of qualitative distances onto metric distances have been rather abundant in geographic information science and computer science (e.g., Gahegan, 1995; Robinson, 1990, 2000; Worboys, 2001). Most of them use principles of fuzzy logic (Zadeh, 1965) to represent the inherent uncertainty and imprecision of proximity spatial relations (e.g., Guesgen, 2002; Guesgen & Albrecht, 2000). A notable exception is Brennan and Martin (2002) who draw on the geometric construct of generalized Voronoi diagrams with crisp grades of closeness to qualitatively represent absolute binary proximity relations. Recent research has suggested that human beings consider the context of the proximity perception while reasoning about proximity. Discussion and analysis by Sharma, Flewelling, and Egenhofer (1994), Gahegan (1995), Hernandez, Clementini, and Felice (1995), Clementini, Felice, and Hernandez (1997), and others have highlighted the importance of *context* in qualitative spatial reasoning in general and in proximity modeling in particular. Yao and Thill (2005) expand on these principles and estimate an ordered logit regression model of qualitative proximity on the basis of the metric distance measure and of several variables describing the query context. The main aspects of this model are summarized and used in Section 4 for a prototype implementation.

3. Qualitative locations and qualitative spatial query

3.1. Qualitative locations

It is not uncommon that people use combinations of qualitative and quantitative information to refer to locations. This is particularly true when a location whose exact location information is unknown, while its qualitative spatial relations to other locations are known. We define qualitative locations (QL) as the reference of locations using their qualitative spatial relations with other features. In this paper, we will discuss the use of qualitative locations in spatial queries and introduce a mechanism to handle QL-based qualitative spatial queries.

When a user expresses a query about a feature, there are only two possibilities: the feature is known or it is unknown. Here "known features" include those spatial features for which the user knows the name, address, or any other information used for georeferencing in the geospatial information system. Unknown features refer to spatial features for which such information is not in hand. Under the first possibility (the feature is known), the feature is already georeferenced and is therefore ready to be identified in the system. If the second possibility appears (the feature is unknown), the user may try to describe the spatial relations between this unknown feature and other known feature(s) to the spatial information system. For example, a park can sometimes be described as "between school A and company B, to the north of street C".

Because of the qualitative nature of a QL, the target spatial features of a qualitative location can consist of a set of spatial features with exact or inexact boundaries. Each feature in the set can be associated with a descriptor of the degree to which the judgment "this feature is the target of the qualitative location" is true. Qualitative locations in our discussion enable two types of spatial data management and manipulation tasks. The first is to retrieve locations through their qualitative spatial relations with other known features (qualitative spatial query). The second possible task is to store qualitative locations in a spatial database with the information of qualitative spatial relations. For instance, a general area believed to hold rich underground petroleum deposits cannot be pinpointed to exact sites or boundaries. Locational information on this area can be stored in a spatial database using the qualitative spatial relations of this area with its surroundings. The rest of the discussion in this paper emphasizes the enhancements in the area of qualitative querying specifically for qualitative locations defined with qualitative spatial relations.

3.2. Qualitative spatial query with QL

Let us consider the following examples of queries with QL:

Where are military forts to the *northeast* of place S?
Find a *nearby* gas station.

Here, "northeast" is a directional relation and "nearby" is a proximity relation. Current spatial information systems are not able to directly handle expressions like these because the former incorporate mostly just metric reasoning methods, while the latter are phrased in qualitative terms. The inability of current spatial information systems to handle qualitative spatial relations calls for new capabilities for qualitative spatial queries in the systems.

The importance of handling queries with qualitative locations in geospatial information systems is at least threefold. First of all, it is consistent with people's spatial perception habits. With qualitative locations, people can now formulate queries in the same way they generally do in every day life. Qualitative location requires qualitative information on how the target location is spatially related to some other known locations. In other words, qualitative location deals with situations when we do not know much about the target location (or feature) but we have some qualitative knowledge on spatial relations between this feature and some other known features. People can also store qualitative descriptions of location into a spatial database, without first being translated into a metric approximation. In a QL-enabled spatial information system, the need of user training is lessened. Better and greater use of spatial information technologies can be anticipated.

Secondly, it complements existing searching methods by creating new searching paths and by relaxing search criteria. In a current geospatial information system, a search is usually isotropic or along directions that have been defined by underlying networks. In a system with QL, it will be possible, for example, to search along some sectors of the surrounding area of a reference location by using directional spatial relations. QL also allows searches through specific paths by using topological relations. Furthermore, QL can be used to relax rigid search criteria thanks to qualitative proximity relations. For example, in current geospatial information system, one can search for "the closest gas station". However, the outcome may be *closest* but not *close*. Or, it is possible that the outcome gives us the closest gas station but fails to identify another bigger and better station that sits just across the street from the closest one. By using qualitative proximity relations in the search, the results can include all the gas stations with different degrees of "closeness". Users are then in a position to make use of these more comprehensive search results.

Thirdly, QL makes it possible to add other qualitative modifiers in a spatial query and reasoning. In current geospatial information systems, a user has to give accurate source information on the name or address of a feature in order to geocode it. The georeference has to be unique. Thus, there is no room for a modifier or descriptor to be placed in a query. However, the query result of a qualitative location may contain multiple spatial features and every location in the current geospatial information system may get more than one way of expressing itself as qualitative location. For example, there might be several gas station locations that meet the requirement of qualitative locations phrased "a gas station close to the University at Buffalo (UB) Campus". Similarly, a gas station can also be qualitatively referred as "close to UB", "north of, and close to the Audubon Public Library", or some other QL expressions. Because multiple locations can be assigned to a QL, other qualitative modifiers (such as *a little*, *very*, etc.) or descriptors (such as *good quality*) can be used in combination with the qualitative spatial relations to further narrow down the target locations. For example, with QL, the user can formulate a spatial query such as "where are nearby and good quality Italian restaurants?" or "please find an easy-on easy-off nearby gas station". The term "nearby" infers a proximity spatial relation. A QL-enabled geospatial information system may identify multiple "nearby" Italian restaurants and gas stations as the target spatial features. The other modifiers "good quality" and "easy-on easy-off" can be used to further grade (using fuzzy logic, for instance) each target location.

To summarize, we narrowly defined QL as "reference of locations using their qualitative spatial relations with other known locations". We propose to include the capability of handling qualitative location in future geospatial information systems. It complements existing query techniques in the systems. The inclusion of QL has the merit of expanding the capabilities and usability of spatial technologies.

3.3. Conceptual framework for qualitative spatial query with QL

Several possible strategies exist to facilitate queries with QL in spatial information systems. One option is to disregard all the achievements of three decades of research with quantitative spatial information technologies and begin anew by creating new systems rooted in qualitative information. There is little chance this would happen, given the considerable intellectual and financial investment made in these legacy systems. A less radical strategy advocated here rests on the view that qualitative spatial query functionality can be realized incrementally by adding and updating models of qualitative spatial reasoning to existing geospatial information systems.

The notion of Qualitative Location is conceived to enable users to query and reason with qualitative spatial relations. The operation of queries with QL can be decomposed into two steps illustrated in Fig. 1. Recognizing the linguistic terms and translating them into computer-understandable language is the first step. The sole purpose of this task is to make the system understand the terms appearing in

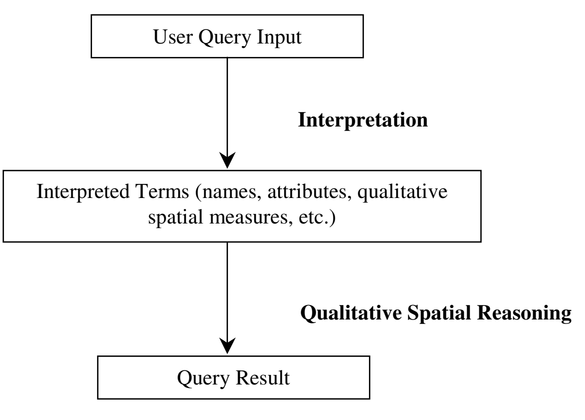

Fig. 1. A two-step solution for queries with qualitative terms.

the user's query input. After this step, a query is decomposed into elements such as place names, attributes, measures, and spatial relations. Techniques in information technology, such as indexing and retrieval techniques, and word pattern recognition techniques, can make a substantial contribution to the fulfillment of this interpretation task.

The second step is to apply rules of qualitative reasoning to the spatial relations that have been recognized in the previous step. The reasoning capability of models of qualitative spatial relations is critical to complete the task of qualitative spatial query and reasoning. We argue that prior and ongoing research on qualitative spatial reasoning, which was reviewed in Section 2, can directly be used for this purpose and start populating the model bases in the qualitative spatial reasoner. To keep pace with future developments in qualitative spatial reasoning, we argue that the system should be designed with an open architecture so as to allow for new models and extensions of existing models to be incorporated into the system easily.

The conceptual framework depicted in Fig. 2 takes advantage of available spatial technologies and of models in qualitative spatial reasoning. The spatial information system provides data and tools of conventional spatial data handling. This legacy system is complemented by two modules called *Language Interpreter* and *Qualitative Spatial Reasoner* whose functions are to carry out each of the two tasks identified in the two-step solution in Fig. 1. The language interpreter decomposes a user query into several types of elements: place names, attributes, measures, qualitative spatial relations, numbers, logical operators (e.g., AND, OR), and translated fuzzy linguistic expressions. If there is no qualitative spatial relation in the query, the language interpreter will pass the information to the spatial information system where the query will be handled with traditional methods. On the other hand, if qualitative spatial relations are found, the language interpreter module sends the interpreted data to the qualitative spatial reasoner.

The core of the reasoner is a multi-level, modular model base. The model base is populated with multiple qualitative reasoning models compatible with each particular type of qualitative spatial relations, such as topology, geographic proximity, cardinal directions, and others. The central control unit (CCU) headquarters the reasoner module and coordinates the reasoning process. The major responsibilities of the CCU includes the following: (1) to dispatch tasks to the right qualitative spatial reasoning model(s) in accordance with the information received from the language interpreter; (2) to dialog with the spatial database; and (3) to synthesize results received from the reasoning model(s) and/or from the traditional part of the spatial information system. For instance, if the information from the interpreter indicates that it is a distance type of query, the CCU will select a model from the proximity model base. When multiple models exist in a model base, the CCU must determine the most appropriate one(s) given the task at hand. There are several possible designs for the model selection. One possibility is to allow user intervention to make the choice. Another possibility is to exercise each and every model and choose the ones that give the "best" and most consistent results (some models may not work for a specific situation and therefore will not yield good results). Yet, another approach could involve case-base reasoning through which the situation on hand is matched

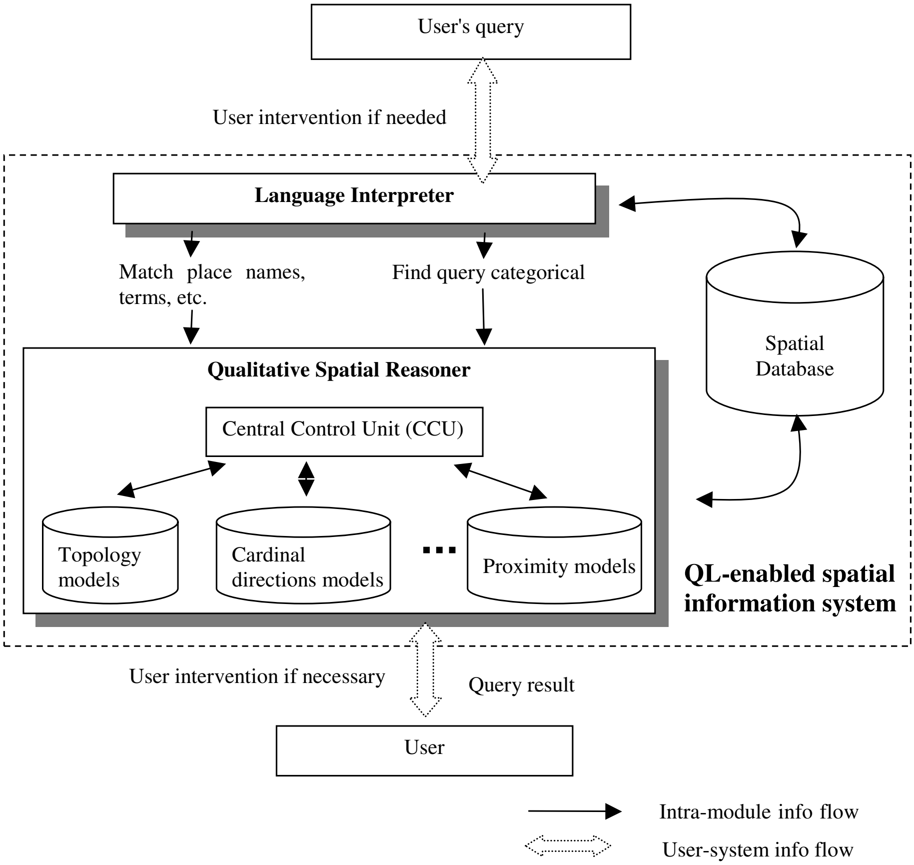

Fig. 2. Proposed framework of a QL-enabled geospatial information system.

on the basis of the query content and context to archived cases that were successfully resolved.

4. A case study and prototype

To illustrate how the principles of the conceptual framework of qualitative spatial query with QL can be used in practical applications, we discuss a concrete example involving qualitative spatial queries, along with the prototype developed to implement it in a GIS system. In the prototype, we populate the model base with a context-contingent proximity model.

As discussed in Section 3 our proposed framework of QL-enabled spatial information system integrates a language interpreter module and a qualitative spatial reasoner module. While the feasibility of the first module has been demonstrated in prior studies (e.g., Wang, 2003), this prototype focuses on this second module—the qualitative spatial reasoner. When an interpreted qualitative spatial relation is passed to the reasoner, the latter will call a corresponding model from the library of spatial reasoning models to reason about the spatial relation in the query. Therefore, the key issues here are to develop or identify appropriate qualitative spatial reasoning models, and to implement them (populate the model library) in the GIS system. In this case study, we incorporate a proximity model capable of capturing the context of the query and implement it in the QL-enabled GIS prototype. The outcome of a sample query instance is presented and compared with that of its crisp counterpart.

4.1. Constructing a context-contingent proximity model

It was discussed in the review section that an important characteristic of proximity spatial relations is their dependence on the contextual circumstances surrounding the spatial query. For example, whether a person perceives the length of a potential trip as "near" or "far" is influenced by a variety of factors, including the actual trip length, modes of transportation available to this person, the type of activity to be conducted on the proposed trip, and many others. Yao and Thill (2005) constructed and empirically validated a context-contingent proximity model that handles such dependencies. The key features of this model are now summarized.

The context-contingent proximity model is based on a questionnaire survey of a random sample of undergraduate students conducted in the University at Buffalo, The State University of New York (Yao & Thill, 2005). Distance perception expressed as linguistic term (*very near*, *near*, *normal*, *far*, and *very far*), together with context information of each proximity perception were collected in the questionnaire survey. The proximity relations were elicited from the survey respondents for hypothetical home-based trips in the Buffalo, NY, metropolitan area. Each hypothetical trip was designed to be consistent with a predefined trip scenario. Data for eleven contextual factors were collected for each trip scenario, including factors related to the built environment and the trip, and factors related to the person assigned the task of qualitative evaluation of trip lengths.

The ordered logit regression model predicts the probabilities of five proximity relations for a given metric network distance and the context variables. The calibrated model is shown in Eq. (1).

$$\begin{aligned}
&\mathrm{logit}(p_1) = 0.195 - y \\
&\mathrm{logit}(p_1 + p_2) = 1.725 - y \\
&\mathrm{logit}(p_1 + p_2 + p_3) = 3.739 - y \\
&\mathrm{logit}(p_1 + p_2 + p_3 + p_4) = 6.445 - y \\
&p_1 + p_2 + p_3 + p_4 + p_5 = 1
\end{aligned} \tag{1}$$

where p_1 through p_5 are the probabilities that a given metric distance be perceived to be *very near*, *near*, *normal*, *far*, and *very far*, respectively, and

$$
\begin{aligned}
y = {} & 0.2\text{Dist} - 1.6\text{car} - 0.6\text{Act1} + 0.63\text{Act2} + 0.1\text{Act3} - 0.57\text{Act4} - 0.03\text{Act5} \\
& + 2.42\text{transp1} + 1.2\text{transp2} + 1.99\text{transp3} + 2.38\text{Area1} + 1.89\text{Area2} \\
& + 1.73\text{Area3} + 0.93\text{Area4} + 0.49\text{Gender} + 0.21\text{Ethnicity1} \\
& + 0.66\text{Ethnicity2} - 0.93\text{Ethnicity3} + 0.6\text{Ethnicity4}
\end{aligned}
$$

where Dist is the metric network distance, car, Act1 through 5, transp1 through 3, Area1 through 3, Gender, and Ethnicity1 through 4 are interval or dummy variables of the significant contextual variables.

4.2. Prototyping

Using Visual Basic and MapObjects, we implemented the above proximity model in the proximity model base of the prototype. Fig. 3 shows the prototype interface when a query is evoked. We use the street network of Buffalo in this example because that is the context to which this specific proximity model applies.

Because the proximity perception is context-contingent, a system with this model will need to obtain context information from a user profile, through interactive

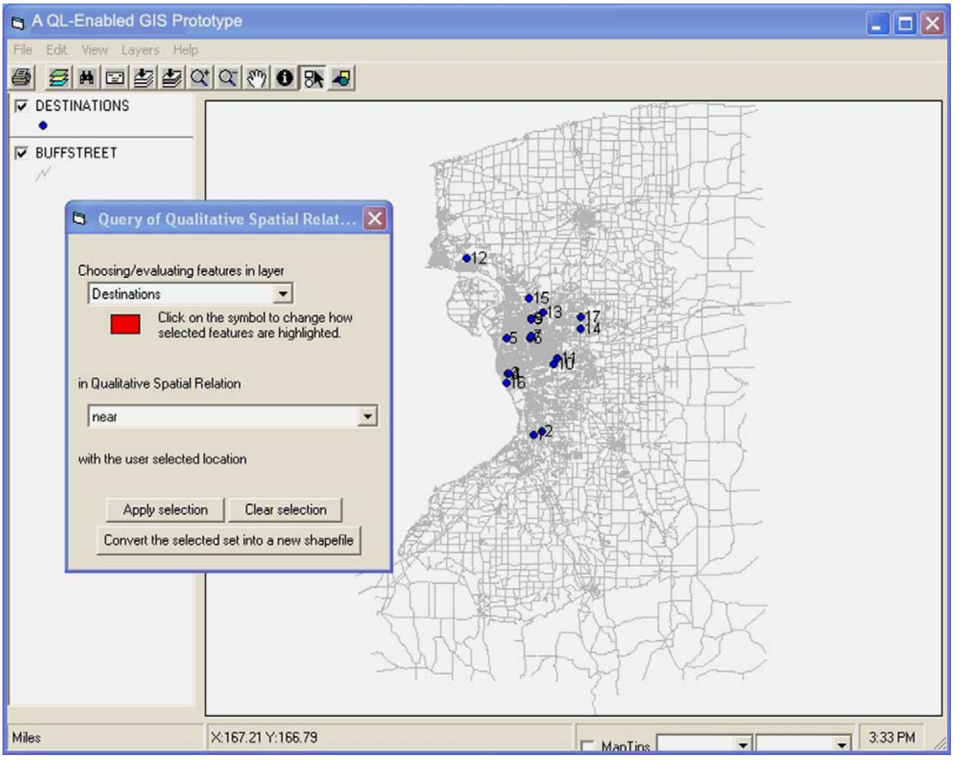

Fig. 3. Prototype interface.

user-machine communication, or a combination of both. This prototyped system uses a user profile, which can be a good option if the system is to be deployed for personal use, for example, in PDAs or as part of a wireless location-based service. Fig. 4 describes the data flow on the prototype when a proximity relation is part of the user query. The user input contains information on the reference location (where the perceiver stands), the type of features to be found (e.g., a public park), and the proximity relations between the reference location and the target features. When the GIS has determined that this is a query about qualitative spatial relations, it will pass the information to the qualitative spatial reasoner, which proceeds by first identifying an appropriate spatial relations model for the type of spatial relations. In our prototype, the model to be used will be the proximity model expressed in Eq. (1). The model produces the probabilities of a target feature being perceived as the specified proximity relations to the reference location. All spatial features with a probability above a certain threshold (0.5 in the prototype) are visualized in the map as the final query result, together with the probability information.

To demonstrate how the prototype works, we present the example of a white male individual searching for "nearby" parks. He has a car at his disposal and plans to drive to the park. He is familiar with the surrounding area. The prototype calls the proximity model as described in Eq. (1). A series of likelihood values of different

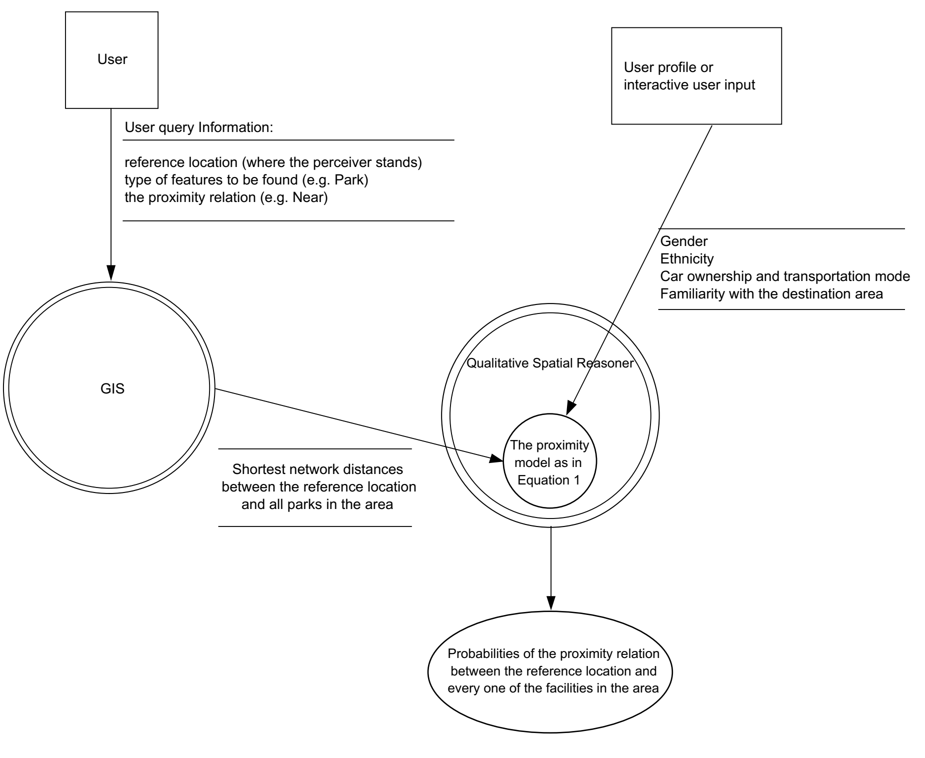

Fig. 4. Data flow of a query with proximity relation in the prototype.

Table 1
Likelihood of being perceived as "near by park" from the reference point as shown in Fig. 5

ID	Likelihood ("near")
1	0.003
2	0.004
3	0.045
4	0.044
5	0.153
6	**0.315**
7	**0.358**
8	**0.541**
9	**0.506**
10	**0.160**
11	**0.223**
12	0.029
13	**0.707**
14	**0.506**
15	0.610
16	0.027
17	**0.663**

proximity relations are computed. Table 1 shows the list of likelihood values for the proximity relation "near". Highlighted are 9 parks within the metropolitan area whose likelihood values are greater than 0.5. The parks are also represented as circle symbols in Fig. 5. The sizes of the circles are proportional to the likelihood of being perceived as "near".

Fig. 5 shows the query result of finding public parks that are "near" to a user specified location. The solid square in the middle of the map display is the user specified reference point, which is the location where the individual "stands" and perceives distances. The above example explains how the prototype handles a query with the qualitative spatial relation "near". Similarly, the prototype can handle "far", "very far", as well as other proximity expressions.

Given the higher investment involved in QL-enabled GIS, it is appropriate to seek to establish whether the outcome of a QL-based GIS query is an enhancement over the outcome of an equivalent "crisp" query. In the case of the illustrative example used here, the latter would take the form of a search for the "nearest" park or parks within certain distance in the Buffalo metropolitan area with respect to the reference location. Although the query of quantitative relation "nearest" is very useful, it is not a panacea for all proximity-related queries. In some instances, the "nearest" location may turn out not to be "near" at all. Furthermore, the result of a qualitative query (say, "near" relation) usually consists of multiple features, each one with a different degree of "nearness". It is therefore possible to also differentiate features on the basis of some other criterion and combine this second rating with the proximity score. The decision-maker is then in a position to consider trade-offs between criteria, either autonomously or with the assistance of multicriteria decision-making models implemented in a custom spatial decision-support module of the GIS, if available (Malczewski, 1998; Thill, 1999). For instance, the individual in the above

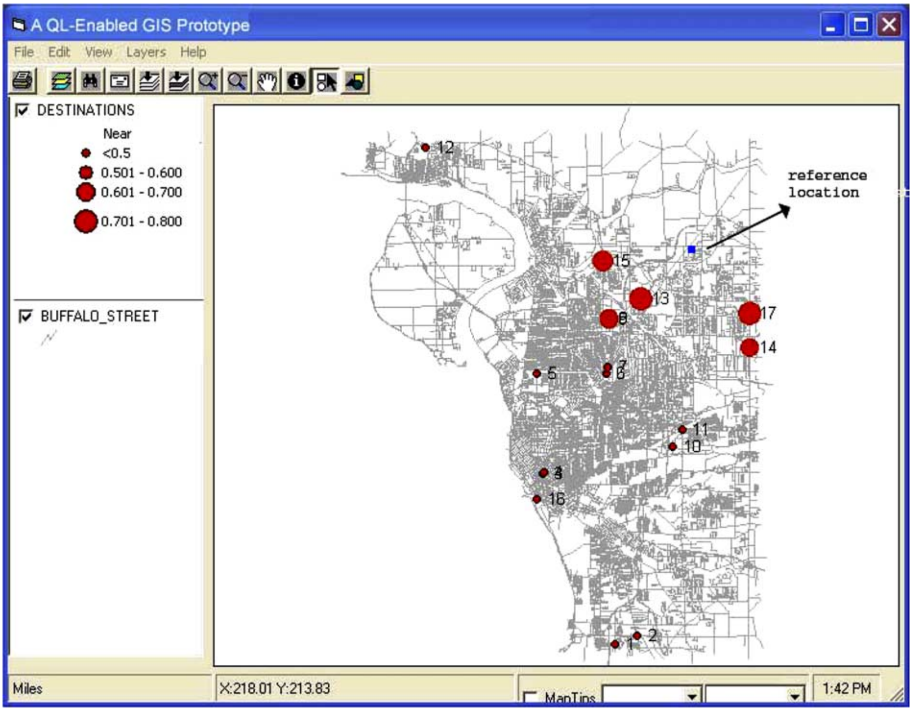

Fig. 5. Query results of finding nearby parks.

example may modify his query into "find *nearby* and *low crime rate* park(s)". In this case, the degrees of nearness of all nine public parks can be combined with some crime rate measurement into a weighted average index on the basis of which the final result can be derived. The quantitative query on the "nearest" facility cannot accommodate this sort of situation. The "within a certain distance" type of quantitative query gives multiple results but has at least two shortcomings in this case. First, the threshold distance for "near" (or other proximity relation) has to be arbitrarily provided by the user. Secondly, it does not consider context factors of a proximity relation. Hence, a QL-enabled GIS can be expected to offer capabilities not currently available in metric GIS.

5. Conclusions

This paper introduces the new concept of Qualitative Location and proposes a solution to queries associated with QL. We aim to expand the capabilities of current spatial information systems in handling qualitative spatial queries expressed in natural language. To handle qualitative spatial query with QL, we propose a conceptual framework that takes advantage of models of qualitative spatial reasoning to bridge the gap between conventional metric spatial information systems and the general public's query of spatial relations in natural language. Our conceptual framework of a QL-enabled system consists in coupling qualitative spatial reasoning models with metric spatial information systems. From a literature review of qualitative spatial reasoning models, we contend that the current state of knowledge on qualitative spatial reasoning provides some of the necessary reasoning capabilities for all types of spatial relations, but more models with proven external validity must be added to our qualitative-quantitative translation toolbox.

The novelty of this work is to bring the general public's Naïve geographical view of their environment into spatial information systems. Accordingly, the QL-based query mechanism will effectively contribute to bringing spatial information systems to the general public. In this regard, the research contributes to the research agenda set forth in Naïve/Common-Sense Geography.

The paper presents a conceptual framework and demonstrates its use with an example prototype. This prototype implements a context-contingent proximity model from a case study. The proposed conceptual framework is a starting point to equip the quantitative spatial information systems with qualitative spatial query capability. We formulate the hope that this paper will stimulate the GI Science research and industry community to build upon the concept of qualitative location in further research and to implement it in real-world spatial applications.

It is our contention that the time is right for full-scale prototypes of QL-enabled GIS on the basis of the conceptual framework advanced in this paper. Understandably, many research challenges stand in the way to the widespread adoption of QL for information query and data storage. We indicated in Section 3.3 that different approaches exist to selecting models of qualitative spatial reasoning from the model base. User-intervention, comprehensive comparison, and case-based reasoning were suggested earlier. At this time, little is known of the advantages and drawbacks on each design, whether some designs are always superior or inferior to the others, the conditions for best performance of each design, and even the specific modality of implementation of a more complex approach like case-based reasoning.

The cursory review of the state of research in qualitative spatial reasoning conducted in Section 2 indicated that several existing models can advantageously be used to populate the model base of the CCU in the proposed framework. However, our understanding of human spatial cognition needs to move to the next level to give us all the necessary tools to map qualitative to quantitative spatial relations, and vice versa. One can point to models of qualitative spatial relation between entities with indeterminate boundaries as a significant research need in this respect. Most current qualitative spatial reasoning models implicitly make the assumption that all places and spaces referenced in queries have crisp boundaries. However, many entities in the real world have indeterminate boundaries. Some models and frameworks have been proposed to cope with boundary indeterminacy (Burrough & Frank, 1996) and some methods have also been proposed to handle imprecisely defined regions in qualitative spatial reasoning models of topological relations (Bittner & Stell, 2000). However, the developments are made of bits and pieces, and many research issues remain to be studied to extend the spatial reasoning models for entities with indeterminate boundaries. Another area where models are lacking is that of the temporal aspects of reasoning. The implicit assumption so far has been that qualitative spatial relations are all about space, and space only; no consideration is given to the temporal aspect. However, temporal reasoning is often embedded in human beings' daily language, together with spatial reasoning. For example, people may query for places whose past they have knowledge about. Models that deal with qualitative spatio-temporal reasoning are necessary for this purpose.

The recognition that qualitative information queries can be performed in GIS does not imply the death of quantitative spatial reasoning in GIS. While we discussed various circumstances where qualitative information querying would be better suited than a quantitative approach, we did not establish the extent to which this may be the case. As QL-enabled GIS evolves to become a reality ready to be placed in the hands of users with no training in spatial technologies, it will become necessary to establish the natural domains of applicability of each approach to reduce the risk of misuse of the technology.

The emphasis of this paper has been on using QL to handle information queries. It was indicated, though, that the same principles can serve to capture and store qualitative information about spaces, places, and spatial relations without a reduction to metric dimensions to fit the constraints of current metric spatial information systems. The exact modalities of use of QL for this purpose remain to be fully identified at this time. Qualitative data storage with QL also brings to the forefront of GI research issues on qualitative data models, user-machine interfaces to communicate qualitative information, and of representation of qualitative spatial relations on the map display of the metric GIS. All these issues form a substantial agenda for future research.

Acknowledgements

We are grateful to Dr. David Mark, who inspired this work and provided invaluable suggestions at critical stages of this research.

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