Addition of the Directionality Concept in Spatial Queries on SDMSs Using the Union of the Cone-Based and Projection-Based Models

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Abstract. *This paper describes a proposed model for defining directional relationships between geometries into Spatial Data Management Systems (SDMSs) uniting the characteristics of the Cone-Based Model and the Projection-Based Model. The proposal also includes the implementation of the created model built as SDMS's extension, unlike other existing implementations which are produced in the form of external SDMS tools.*

1. Introduction

Directional relationships are strongly linked to spatial queries and spatial reasoning in general [Tang et al. 2008], and are naturally perceived by the human being. Directional relations concern the order in which geographic entities are willing.

One of the problems in dealing with directional relationships is that, unlike the case of topological relationships where there seems to be a widely accepted set of relationships [Egenhofer et al. 1990], there is no unified definition of direction relations [Theodoridis et al. 1996]. As a consequence of this lack of unification, there are several models that define the directional relationships, each with their own characteristics.

This work aims to use the Cone-Based and Projection-Based Models in order to create a hybrid conception that both utilises their respective advantages and reduces their respective limitations. Subsequently, the intention is to carry out the implementation of a framework incorporating the reasoning established, which integrates practical content into the work. The created framework is reusable, and for that, this study will implement this directly into the Spatial Data Management System (SDMS), so it can not only be used by any third party software, but also so its functionality can be merged with the existing system in the SDMS. This way, it is possible to use the functionalities related to directional relationships coupled with the functionalities geared towards topological and metric relationships, already well accepted and implemented by SDMSs, creating the possibility of hybrid spatial queries.

2. Theoretical Foundation and Related Work

2.1. Models for Definition of Directional Relationships

According to Xia et al. (2007), the basic models for defining directional relationships fall into two major categories: Cone-Based Models and Projection-Based Models. The Cone-Based Models partition the space by using lines with an origin angle α, as shown in Figure 1. Typical models include the 4-direction Model, Figure 1(a), the 8-direction model, Figure 1(b), and the triangle model, Figure 1(c) [Tang et al. 2008]. The Cone-Based Models can give an accurate identification of directional relationships in the case of point geometries, whereas misleading directional relations may be produced when reference objects are lines or polygons. [Tang et al. 2008].

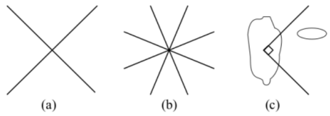

Figure 1. Cone-Based Model

The Projection-Based Models partition the space by using lines parallel to the axes [Spiros et al. 2007]. The space around an object reference *A* is partitioned into nine areas: north (N_A), northeast (NE_A), east (E_A), southeast (SE_A), south (S_A), southwest (SW_A), west (W_A) e northwest (NW_A), that refer to the cardinal and ordinal directions, and one additional region corresponding to the Minimum Bounding Rectangle (MBR) of the reference geometry (0_A), as shown in Figure 2. In this category, the MBR Model is prominent [Tang et al. 2008].

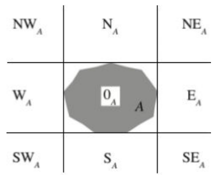

Figure 2. Projection-Based Model

The MBR Model expresses directional relationships by the relationship between the MBR of the reference object *A* and the primary object *B*. Egenhofer et al. (2000) introduces a MBR Model, which uses the 9-intersection matrix [Egenhofer and Herring 1991], projecting a grid over the concerned geometries. This model has the flexibility for the attribution of weights if an object *B* occupies the space of more than one direction using the following formula:

$$Dir_{RR}(A,B) = \begin{bmatrix} \frac{area(NW_A \cap B)}{area(B)} & \frac{area(N_A \cap B)}{area(B)} & \frac{area(NE_A \cap B)}{area(B)} \\ \frac{area(W_A \cap B)}{area(B)} & \frac{area(0_A \cap B)}{area(B)} & \frac{area(E_A \cap B)}{area(B)} \\ \frac{area(SW_A \cap B)}{area(B)} & \frac{area(S_A \cap B)}{area(B)} & \frac{area(SE_A \cap B)}{area(B)} \end{bmatrix} \quad (1)$$

Egenhofer's work formalised a method concerning the treatment of geometries that occupy more than one direction according to the projection. However, the work was theoretical, not presenting implementation, either in third party software or directly on a

SDMS. Furthermore, in the projection, as one moves away from the reference geometry, the areas of the ordinal directions become too large in comparison with the cardinal directions areas. Moreover, the MBR Model is not suitable for treating points, since they do not actually have MBR.

Zhu et al. (2012) presents a model for defining directional relationships between geometries based on Geo-Ontologies (gazetteers). In this model, the directional relationships are determined from secondary queries made on Geo-Ontologies. The Zhu's model is interesting, primarily due to the fact that adding semantics to the research enables the tapping of knowledge pertaining to the directionality in the objects represented in the ontology. However, the addition of this semantic implies the existence of data arranged in the form of ontological basis on the studied area – this could potentially result in existing spatial databases becoming incompatible with this model, if there are no ontologies regarding their spatial context in question. Furthermore, the ontological database is external to the SDMS, resulting in the need for two databases, one spatial and one ontological, separated to perform the search. Thus, integration with the existing resources of the SDMS becomes problematic and complex. The model is theoretical, being treated the implementation as a future work.

2.2. Implementation in SDMSs

The implementation of additional functionalities for Spatial Queries can be made in several ways, however the possibility of creating such features as SDMS extensions from their own source code is interesting. This approach brings benefits, among which are as follows:

- Reuse of existing SDMS resources in the extensions creation;
- Possibility of performing SQL/SF-SQL queries using a combination of the pre-existing functionalities and the functionalities added by the extensions directly in SDMS without the need for a third party software;
- Transparent utilisation of the extensions by third party software, since extensions would be incorporated into the SDMS;
- Distribution facility of the extensions since these (after compiled) would be compatible with any valid installation of the SDMS used as the source for the development.

This implementation model allows of created extensions can be positioned in the GIS communication scheme as shown in Figure 3.

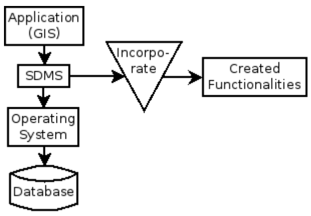

Figure 3. Illustration of the layer in which are inserted the extensions

3. Proposed Work

The proposed work contains four steps, from the conception to the implementation of the model. These steps are explained, in general terms, as follows:

Formal definition of the model: In this step, the paper formalises the proposed model that combines the features of the 8-direction Cone-Based Model and Projection-Based Model introduced by Egenhofer et al. (2000).

Elaboration of a pseudo-implementation of the functionalities: The pseudo-implementation should be generic to the point of allowing it to be translated into a variety of programming languages and on different layers – in this case, the third party application or database.

Development of functionalities in a SDMS: The implementation will be made from the source code of PostgreSQL and PostGIS. Uchoa et al. (2005) puts this set forth as a robust option for enterprise GIS implementations; a suggestion that was considered as an option for the work's implementation. PostgreSQL has also been adopted due to its flexibility in developing new modules [UCHOA et al. 2005], counting on architecture specifically designed for this purpose called PGXS – a construct that facilitates the integration and distribution of the created extensions. To use this architecture, you must create the following features: Control File, SQL Descriptor, Makefile and the Created Extension file (source or compiled), as shown in Figure 4. If the source code of the created extension is used, the Makefile should contain an entry specifying the compilation process and the compiler.

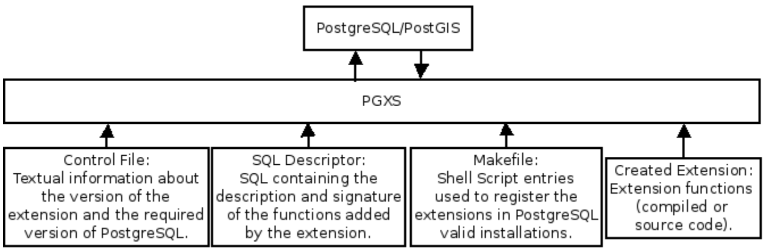

Figure 4. Requirements of the PGXS architecture

Development of a GIS module that uses the created extension: Aims to validate the functionalities added by the SDMS extension.

3.1. Current Status

In order to ascertain where the projection grid and the conic grid diverged, it was necessary to overlay the former with the latter; this procedure was used as a way to reduce the discrepancy between the existing areas in the Projection Model. In the created model, the disagreement areas were named in correspondence with Table 1, where the ordinal directions, according to the projection, are given by $P(NE_A)$, $P(NW_A)$, $P(SE_A)$ and $P(SW_A)$, and the cardinal directions according to the Cone by $C(N_A)$, $C(S_A)$, $C(E_A)$ and $C(W_A)$. The remaining areas of divergence were not considered because, if they were, it would remove an area of cardinal directions, thereby reducing the decrease of discrepancy that was achieved.

Table 1. Nomenclature of divergence areas according to the created model

Region	Name	Notation
$(P(NE_A)\bigcap C(N_A)\neq Ø)\vee(P(NW_A)\bigcap C(N_A)\neq Ø)$	*slightly_north(A)*	N_A^S
$(P(SE_A)\bigcap C(S_A)\neq Ø)\vee(P(SW_A)\bigcap C(S_A)\neq Ø)$	*slightly_south(A)*	S_A^S
$(P(NE_A)\bigcap C(E_A)\neq Ø)\vee(P(SE_A)\bigcap C(E_A)\neq Ø)$	*slightly_east(A)*	E_A^S
$(P(NW_A)\bigcap C(W_A)\neq Ø)\vee(P(SW_A)\bigcap C(W_A)\neq Ø)$	*slightly_west(A)*	W_A^S

This formalisation adds regions for the standard definition of Projection-Based Models and can be used for relations between lines and polygons. It is, however, not possible to use said model if there are relationships involving points as reference geometry.

The formula used by Egenhofer in his work also applies to the created model. This is due to the fact that, though arranged in a matrix form, the value corresponding to each cell follows the pattern “geometry area within the region in question” divided by “geometry area”, thus easily fitting into the created model.

The implementation of the created model, still in the initial stage, is made through spatial functions that indicate to what extent a geometry is in a certain direction. These functions should be used in SQL queries such as “SELECT E1.name FROM state E1, state E2 WHERE stx_slightly_north(E2.geometry, E1.geometry) >= 0.2 AND NOT st_touches(E1.geometry, E2.geometry) AND E2.name ilike('GOIAS') AND E1.country_name ilike('BRAZIL');”. Figure 5 illustrates the result of this query, highlighting the reference geometry, Figure 5(a), and the return of the query, Figure 5(b), along with the cone and projection grids.

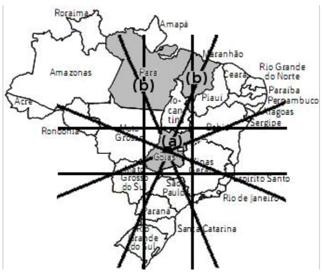

Figure 5. Query used as example shown graphically

In the previous example, it is possible to get a listing of the names of the states of Brazil that have at least one fifth of its area slightly north of the 'GOIAS' state and which do not meet it. The given example uses functions implemented by the extension (stx_slightly_north) and topological functions existing in the SDMS (ST_Touches) in the same query. The implemented functions follow the algorithm in Figure 6 in order to measure to what extent a geometric area is in a direction relating to a specific reference:

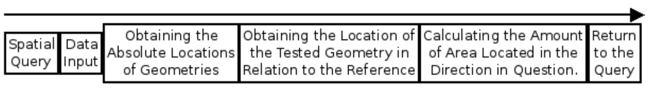

Figure 6. Generic algorithm used in implemented spatial functions

4. Final Considerations

The presented models for defining directional relationships can determine the direction accurately, but with certain limitations. Cone-Models are suitable for point geometries and Projection-Models for lines and polygons, thus opening the possibility to study their characteristics and combine them in order to provide a more global model.

In general, there is a dearth of implementations of the models. Even when performed, is generally concentrated in SDMS external tools unlike this work which focuses on an implementation incorporated within the SDMS. So far has developed a prototype that is only compatible with points as target geometries. In order to improve this work, further studies must be, and are indeed being, conducted at the moment.

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