EXTENDED CONCEPTUAL NEIGHBORHOODS

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ABSTRACT

Based on the smooth transition model for conceptual neighborhood graphs among binary topological relations, an extended model, the movement model, is proposed. A neighborhood relation between two topological relations describes one of the possible movements of one object with respect to the second one. The example of the construction of the graph for line-zone relations is provided. Such extended graphs may be used for conception of analyzers and human/machine dialogue engines for visual query languages for geographical information systems. A prospective discussion gives some insights of their applications in this context.

1 INTRODUCTION

Querying Geographical Information Systems (GIS) is a difficult task. Low level query languages (Arc/INFO scripts (Morehouse, 1985), Space (Apic Systmes, 1996), various SQL geographical flavors) are difficult to use and are reserved for specialists. GUI-based interfaces are usually limited to a predefined set of spatial queries and to the possibility to zoom/unzoom and to pan the resulting map. While well adapted to repetitive and pre-defined usage, such interfaces are not suited for advanced users who are concerned by activities such as datamining on spatial or thematic georeferenced data. Natural language may be thought as a possible solution but it rapidly appears that it is rather difficult for the user to simply specify a spatial configuration of objects (Szmurlo et al., 1998, Egenhofer et al., 1994, Mark et al., 1995). Furthermore, natural language implies many difficulties in analysis (references, anaphora, writer’s cultural background, etc.). Finally, the most natural way to specify a set of spatial constraints (i.e.: a query) appears to be a graphical representation of the configuration: a sketch, a schema. Such query interfaces belong to the family of Query-By-Example (QBE) languages where an example of what is searched is “shown” to the machine. While intuitive for the users, the main problem is the interpretation of what the user actually is looking for.

Querying a geographical database requires the specification of two kinds of constraints: the spatial constraints and the thematic constraints. Spatial constraints specify what are the spatial relationships between the objects: relative positions (A is north to B), topological relations (A is in B, A crosses B, etc.), metric relations, etc.. Thematic constraints specify the geographical type of the object (e.g.: road, town) and constraints for alphanumeric data (population of the town less than 10,000 inhabitants, for example). In the past decade, there have been proposed several projects for querying spatial databases with visual QBE-like interfaces.

Lee and Chin proposed a constrained drawing tool (“à la MacDraw”) for building the spatial configuration (Lee and Chin, 1995). This interface was “object driven” in the sense that the user had total freedom to draw the objects; it was the machine which was in charge for analyzing the drawing and extracting the spatial relationships. The drawback of this interface was the way for specifying thematic constraints which was performed with a more or less SQL-like language, difficult for non specialists. Calcinei et al. developed a prototype, Cigalles, of an iconic language where any spatial object or associated thematic data was represented by an icon (Calcinei and Mainguenaud, 1994). Cigalles is “relation driven” rather than “object driven” which means that before specifying a query, the user has to know which spatial relations he or she wants to express. Egenhofer’s “Spatial-Query-by-Sketch” (Egenhofer, 1996) seems to be the most intuitive interface as it is object driven and the user sketches the spatial configuration with an electronic pen. This interface however requires an important object recognition/interpretation work before the analysis of the configurations actually begins. Finally, we also are currently working on a visual language for GIS querying which is a derivate from Lee’s project: thematic constraints are entered as natural language expressions while spatial constrains are drawn with a constrained MacDraw-like tool. This project, the Geographical Anteserver, was described in (Szmurlo et al., 1998, Szmurlo and Gaio, 1998).

In object driven interfaces the most difficult part is the analysis of the schema in order to derive the spatial relations that are implied by the relative positions of the objects, and finally the interpretation of the schema into a set of spatial concepts. Our analyzer is based on Egenhofer’s et al. work on modelization of topological relations (the 9-intersection model (Egenhofer et al., 1994)), on modelization of conceptual neighborhoods among topological relations (Egenhofer and Mark, 1995) and their interpretation (Mark and Egenhofer, 1994, Mark et al., 1995).

Conceptual neighborhoods based on the smooth transition model (STM) are suited for rough partitioning of sets of topological relations into sets expressing some spatial concepts. As it is based on single movement of sub-parts of objects, it is not flexible enough, however, to express partial or total movements. Our contribution in this paper mainly concerns the the definition of an extension of the conceptual neighborhood graph based on the STM by using a different definition of neighborhoods. Our model is called the “movement model” as it takes into account partial but also entire displacement of an object with respect to another.

This paper is organized as follows. In section 2 we present some basic definitions for the 9-intersection model for topological relations and the graph of conceptual neighborhoods based on the STM for line-zone topological relations. In section 3 we develop the general model and present its application to line-zone relations. Finally, section 4 prospectively discusses the application of this model to spatial concept modelization and usage for human/machine dialogue.

2 BASIC DEFINITIONS

This section briefly presents the definitions used for the construction of topological relations that exist between linear and zonal objects, and the method for building the graph of conceptual neighborhoods based on the smooth transitions model as proposed by Egenhofer et al. in (Egenhofer et al., 1994) and (Egenhofer and Mark, 1995).
2.1 The 9-intersection model

Definition 1 (Part, Proper part)
An object A partitions its embedding universe into three “parts”: A’s exterior (A\(\hat{}\)), A’s boundary (\(\partial A\)) and A’s interior (A\(\overset{\circ}{-}\)).

\(\partial A\) and \(A\overset{\circ}{-}\) are called the “proper parts” of A as their union equals A.

A’s parts are mutually exclusive as the intersection of any part of A with another part of A is empty.

A topological relation \(R_{AB}\) between two objects A and B is defined by the nine possible intersections of A’s parts with parts of B. These intersections can be represented in matrix form as shown in equation 1.

\[
R_{AB} = M_{AB} = \begin{bmatrix}
A\overset{\circ}{-} & A\overset{\circ}{-} \cap B\overset{\circ}{-} & A\overset{\circ}{-} \cap \partial B & A\overset{\circ}{-} \cap B\overset{\circ}{-} & \partial A \cap B\overset{\circ}{-} & \partial A \cap \partial B & \partial A \cap B\overset{\circ}{-} & \partial A \cap B\overset{\circ}{-} & \partial A \cap \partial B
\end{bmatrix}
\]

The notation \(M_{P_A, P_B}\) represents the cell corresponding to the intersection \(P_A \cap P_B\), where \(P_A\) and \(P_B\) are parts of A and B, respectively. Among several topological invariants (Munkres, 1966), that is properties that are invariant upon topological transformations, we consider the values empty (0) and not empty (≠0) for each intersection. This results in \(2^9 = 512\) possible candidate relations, most of them being impossible for topological reasons. For simple zones and lines, Egenhofer et al. did identify 19 line-zone relations, 8 zone-zone relations, and 33 line-line relations. Some line-zone relations are shown on figure 1 along with their matrices (lines as columns, zones as rows).

2.2 Conceptual neighborhoods

An intuitive examination of figure 1 shows similarities among subsets of relations. For example, R5 is “closer” to R9 than to R11: in order to reach R9 from R1, one would only need to move one line’s boundary from Z\(\overset{\circ}{\cup}\) on \(\partial Z\) while to reach R11, it will be necessary to move the whole line’s thought zone’s boundary. Similarly, R7 is “closer” to R11 than to R1. By defining a closeness measure, it might then be possible to build a graph where an edge between R1 and R6 expresses the fact that R6 is close to R1. Egenhofer and Mark (Egenhofer and Mark, 1995) proposed two modelizations for building such graphs. In this paper, we are only concerned with the so-called “smooth transitions” model.

Definition 2 (Extent)
The “extent” of a part \(P_A\) of A in the object B is the set of parts of B that have a non-empty intersection with \(P_A\). The extent of \(P_A\) in B will be noted \(E_B(P_A)\).

This definition implies that \(P_A\) is included or equal to the union of the elements from \(E_B(P_A)\). For example, for relation R11, we have: \(E_B(L) = \{Z^\circ, \partial Z\}\) and \(E_B(L^\circ) = \{Z^\circ\}\).

Definition 3 (Adjacency)
The “adjacency” of a part \(P_A\) of an object A, written as \(\text{Adj}(P_A)\), is the set of parts of A that are directly reachable from \(P_A\).

For a zone Z we have:

\[
\text{Adj}(Z^\circ) = \{\partial Z\}
\]

\[
\text{Adj}(\partial Z) = \{Z^\circ, Z^-\}
\]

\[
\text{Adj}(Z^-) = \{\partial Z\}
\]

The construction of neighbors of the relation \(R\) between a line L and a zone Z consists in “moving” in turn a part of each proper part \(P_i\) from the part \(P_{Z^\circ} \subset P_Z\) of Z with which \(P_i\) intersects on each element of \(\text{Adj}(P_Z)\). “Moving” is practically performed by setting to 0 or to -1 cells in the matrix corresponding to \(R_i\). Such operations may produce non-valid matrices; as the objects are connected, it is necessary to introduce consistency constraints that will correct the matrix:

\[
L^\circ \cap Z^\circ = -o \land L^\circ \cap Z^- = 0 \Rightarrow L^\circ \cap \partial Z = 0
\]

\[
\partial L \cap Z^\circ = 0 \Rightarrow L^\circ \cap Z^- = 0
\]

\[
\partial L \cap Z^- = 0 \Rightarrow L^\circ \cap Z^- = 0
\]

The full algorithm is provided in (Egenhofer and Mark, 1995).

Figure 2 depicts the graph of conceptual neighborhoods obtained by this model.

2.3 Discussion

An interesting point to note is that the graph is oriented as not all the transitions are symmetric (for example \(R_{11} \rightarrow R_{11}\) but \(R_{11} \neq R_{11}\)). The transition \(R_{11} \rightarrow R_{11}\) may seem to violate the principle of the model as a part of \(L^\circ\) moves directly from \(Z^\circ\) to \(Z^-\). This transition is obtained by moving \(\partial L\) from \(\partial Z\) on \(Z^\circ\). Thus, \(L^\circ\) must “follow” (due to consistency constraint 7). On the contrary, \(R_{11} \rightarrow R_{11}\) is not obtained because moving either \(L^\circ\) or \(\partial L\) from \(Z^-\) does never require \(L^\circ\) to fully enter \(Z^\circ\).

The intuitive geometrical interpretation of \(R_7 \rightarrow R_{11}\) is however reasonable. Imagine pulling on the line’s boundary that lays in \(Z^\circ\), then, at some time, the configuration \(R_7\) will be changed into \(R_{11}\), as shown on figure 3. This interpretation corresponds to a translation of the whole line.

If we accept that lines may be moved entirely (translation, rotation, deformation, etc.) and not only partially, then many new transitions may be obtained as for example the one depicted figure 4. Note that a similar approach was also used by Egenhofer and Al-Taha for zone-zone relations (Egenhofer and Al-Taha, 1992).

3 EXTENDED CONCEPTUAL NEIGHBORHOODS BASED ON A MOVEMENT MODEL

This section presents an extended model for building an enriched graph of conceptual neighborhoods of topological relations. As an example, we will use line-zone relations. The model is based on movement of the line with respect to the zone. By the generic term “movement” we mean translation, rotation, expansion, reduction, deformation, etc. of the line. This implies that we will consider independent movement of each proper part of the line either partially or totally as well as simultaneous movement of all proper parts.

This section is divided in four parts. We will give an intuitive idea of the model based on an example and state some notions. Then we will provide a formal definition and its application to line-zone topological relations. Finally, we will prune the graph from non-atomic transitions and present the final graph for line-zone relations.
3.1 Intuitive idea of the model

This section provides an intuitive idea of the model based on the example of relation $R_6$ (see figure 2). For this configuration we have $E_2(\partial L) = \{Z^c\}$ and $E_2(L^c) = \{Z, \partial Z, Z^c\}$. We first consider possible movements of $\partial L$, then movements of $L^c$ and finally simultaneous movements of $\partial L$ and of $L^c$.

Movement of $\partial L$ only

As $E_2(\partial L) = \{Z^c\}$, $\partial L$ will be moved either partially or totally on elements of $\text{Adj}(\partial Z^c) = \{\partial Z\}$, that is $\partial Z$. The movement’s source is the union of elements from $E_2(\partial L)$, that is for $R_6$, $Z^c$. If $\partial L$ moves partially, the target relation is required to respect $\partial L \cap Z^c = -\emptyset$, $\partial L \cap \partial Z = -\emptyset$, and $\partial L \subset Z^c \cup \partial Z$. On the other hand, if $\partial L$ moves totally, the relation must respect $\partial L \cap Z^c = \emptyset$ and $\partial L \cap \partial Z = -\emptyset$, with $\partial L \subset \partial Z$.

As a short hand notation for:
- $Z^c$ is the source of the movement of $\partial L$,
- $\partial L \cap Z^c = -\emptyset$, $\partial L \cap \partial Z = -\emptyset$, and $\partial L \subset Z^c \cup \partial Z$, or in other words that $\partial L$’s destination is the union $Z^c \cup \partial Z$,
- $\partial L \cap Z^c = \emptyset$, $\partial L \cap \partial Z = -\emptyset$, and $\partial L \subset \partial Z$, or in other words that $\partial L$’s destination is $\partial L$,

we will write: $\overset{\partial L}{\rightarrow}(\partial, \partial Z)$. The source of the movement $(\partial L)$ corresponds to the union of elements of $\partial L$’s extent (currently $Z^c$ only); each element of $(\partial, \partial Z)$ is a possible destination for $\partial L$.

The computation of the target relations is performed as follows. For the destination $(\partial Z)$: $M_{\partial L}(\partial Z^c, Z) \leftarrow -\emptyset$ and $M_{\partial L}(\partial Z^c) \leftarrow -\emptyset$; for the destination $\partial Z$: $M_{\partial L}(\partial Z, Z^c) \leftarrow -\emptyset$ and $M_{\partial L}(\partial Z, Z) \leftarrow -\emptyset$. By performing these operations, we obtain $R_{10}$ and $R_{10}$ as neighbors of $R_6$. Note that the destinations $(\partial Z)$ and $(\partial, \partial Z)$ are short hand notations for unions of elements of the extents of $\partial L$ in the zone for the target relations, $R_{10}$ and $R_{10}$ respectively.

Movement of $L^c$ only

As $E_2(L^c) = \{Z^c, \partial Z, Z\}$, the source of the movement of $L^c$ will be written as $(\partial L)$. Let’s call $L^c$, the sub-part of $L^c$ that intersects with $Z^c$, $L^c_{Z^c}$ the sub-part that intersects with $\partial Z$, and $L^c_{\partial Z}$ the third one would remain still (for example move $L^c_{Z^c}$ and $L^c_{\partial Z}$ simultaneously, while $L^c_{\partial Z}$ remains still), then we will move simultaneously all three. As $L^c_{Z^c}$ intersects with $Z^c$, the possible destinations of $L^c_{Z^c}$ in a total or partial movement are in $[\partial, \partial Z]$. Identically, destinations of $L^c_{\partial Z}$ and $L^c_{\partial Z}$ are respectively in $[\partial, \partial Z]$ and in $[\partial, \partial Z]$.

When $L^c_{Z^c}$ moves alone, we will obtain two possible destinations for $L^c$, each of these corresponds to the two possible destinations of $L^c_{Z^c}$ while the two other sub-parts remain still. Thus we obtain the following destination set: $(\partial, \partial Z)$. The notation $(\partial, \partial Z)$ expresses the fact that $L^c \cap \partial Z = \emptyset$, and $L^c \cap \partial Z = \emptyset$ and $L^c \cap \partial Z$ which is equivalent to say that $L^c \cap \partial Z = -\emptyset$ and $L^c \cap \partial Z$. In other words $(\partial, \partial Z)$ is equivalent to $(\partial)$. The same holds for $(\partial, \partial Z)$ and $(\partial, \partial Z)$ which are respectively equivalent to $(\partial)$ and $(\partial)$. With these simplifications rules, we can write that the possible destinations for $L^c$ when $L^c_{Z^c}$ moves alone are in the set $[\partial, \partial Z]$.

Similarly, we will obtain the following respective sets of destinations when $L^c_{\partial Z}$ and $L^c_{\partial Z}$ are moving alone: $(\partial, \partial Z)$ and $(\partial, \partial Z)$.

The next step would consists in moving two sub-parts while the third one would remain still (for example move $L^c_{Z^c}$ and $L^c_{\partial Z}$ simultaneously, while $L^c_{\partial Z}$ remains still), then we would move all three sub-parts. These operations are rather painful when performed by hand; the courageous reader may verify that after simplifications we will obtain:

$$(\partial L) \overset{\partial L}{\rightarrow}(\partial, \partial Z) \cup (\partial, \partial Z, \partial Z)$$
As \( L^o \)'s source is \( \sim o \), the movement toward the destination \( \sim o \) will result in the relation \( R_o \) itself: this transition is the identity transition. The destination \( \sim o \) implies that the target relation must satisfy: \( L^o \cap Z^o = \emptyset, L^o \cap Z^o = \emptyset, \text{ and } L^o \cap Z^o = \emptyset \). The last constraint is unsatisfiable as lines are connected objects. Likewise the smooth transition model, it is necessary to introduce consistency constraints. In this case, constraint 5 (see above) would be used. The destination then becomes \( \sim o^{-} \), which again corresponds to the identity transition. Finally, we end up with three non-trivial destinations: \( \{ \sim o^{-}, \sim o, \sim o \} \).

For destination \( \sim o \) the following operations are to be done:

\[
M[L^o, Z^o] \leftarrow \emptyset, M[L^o, Z^o] \leftarrow \emptyset, \text{ and } M[L^o, Z^o] \leftarrow \emptyset.
\]

The resulting matrix corresponds to a non-existing relation. If we apply the consistency constraints from the smooth transition model, constraint 6 would be used. This constraint moves the interior of the line according to the new position of the boundary. In the present case, however, we are moving the interior of the line: it is the line's boundary which should be moved according to interior's new position and not the opposite. We therefore need to setup a new set of consistency constraints based on the movement of \( L^o \) rather than on the movement of \( O\). For this particular transition, the constraints will be: "if the boundary of the line moves completely from \( Z^o \) on \( O\) and if there was an intersection between \( L^o \) and \( Z^o \), then \( O\) also moves completely from \( Z^o \) on \( O\)." An equivalent constraint will be defined for movements from \( Z^o \) to \( O\). By applying this constraint we obtain \( R_{13} \) as \( R_o \)'s neighbor. Destinations \( \sim o \) directly gives \( R_0 \) as target, and destination \( \sim o \) gives \( R_{12} \) after application of the constraint presented above.

### Simultaneous movement of \( L^o \) and \( O\)

The set of possible destinations for \( L^o \) and \( O\) in a simultaneous movement is the Cartesian product of individual destinations of \( L^o \) and \( O\) that were computed above. Thus, we obtain the following set of couples where the first element is the destination of \( L^o \) and the second of \( O\): \( \{ (\sim o^{-}, \sim o), (\sim o^{-}, \sim o^{-}), (\sim o^{-}, \sim o^{-}), (\sim o^{-}, \sim o^{-}) \} \).

By applying these destinations, we respectively obtain the following neighbors for \( R_0: R_{10}, R_{18}, R_{18}, R_{13}, R_{15}, \text{ and } R_{12} \).

### Conclusion

In this section we constructed the neighbors for the relation \( R_0\). By moving \( O\) only we obtained \( R_{10}, \text{ and } R_{12}; \) by moving \( L^o \) only we obtained \( R_{13}, \text{ and } R_{12}; \) by moving simultaneously \( L^o \) and \( O\) we obtain \( R_{13}, \text{ and } R_{12}. \) Note that \( R_{10}, \text{ and } R_{13} \) have already been produced in the two previous stages. Finally only two new neighbors are found: \( R_{13}, \text{ and } R_{12}. \) As previously consistency constraints must be applied. When a matrix of a non-existing relation is produced, we first apply interior's consistency constraints, then boundary's consistency constraints, in order to obtain two target relations.

### 3.2 The movement model for conceptual neighborhoods

In this section we first propose a general description of the movement model for building the conceptual neighborhood graph among topological relations. In a second subsection we will apply this model to line-zone relations and present the graph. Finally, we will provide some insights for geometrical interpretation of the transitions.

#### The movement model

This section presents the general definition of the movement model. The movement of an object is defined as a movement of any number of its proper parts. In the first paragraph of this section we will define the movement of one proper part. Then we will define the composition of those simple movements in order to make all the object moving.

In order to have a general definition, we extend the definition of topological relations themselves. An object \( A \) partitions the universe into a given number \( p_A \) of mutually exclusive parts \( P^1_A, P^2_A, \ldots, P^n_A \) which union equals the universe. In the graph model, the number of parts was equal to 3. Let \( \Pi_A \) be the set of proper parts of \( A \). (their union is \( A \)). Let \( B \) be a second object which makes a partition of the universe into \( p_B \) parts. The topological relation between \( A \) and \( B \) is defined by a \( p_A \times p_B \) boolean matrix \( M \) which cell \( M[P^i_A, P^j_B] \) represents the emptiness of the intersection \( P^i_A \cap P^j_B \). The foremost application of this extension in our analyzer will be explained later.

We assume furthermore that \( A \) remains still and that \( B \) moves.

#### Movement of a single proper part of \( B \)

Let \( P \) be one of \( B \)'s proper parts, let \( Q_1, \ldots, Q_n, n \leq p_B \) be some elements of \( E_A(P) \), and let \( Q = Q_1 \cup \ldots \cup Q_n \). The extended adjacency of order \( n \) of \( Q \), written as \( A^n (Q) \), is the set of possible destinations of \( P \) in a movement which source is \( Q \). \( A^n (Q) \) is defined as follows.

1. If \( n = 1 \) \( P \subseteq Q = Q_1 \):

\[
A^1(Q) = P \star (\text{Adj}(Q) \cup \{Q\}) - \{Q\},
\]

where \( P \star (E) \) is the set of parts of a set \( E \), from which the empty set had been removed.

As an example, let's consider the relation \( R_0 \) and \( P = O\). In this case \( Q \sim Z^o \) (as \( E_Z(O) = \{Z^o\} \)), \( \text{Adj}(Q) \cup \{Q\} = \{O, Z^o\} \), and finally \( A^1(Z^o) = \{O, Z^o \cup O\} \) (which can be written as \( \{O, Z^o\} \) if we use the shorthand notation defined in section 3.1).

2. If \( n = 2 \) \( P \subseteq Q = Q_1 \cup Q_2 \):

\[
A^2(Q) = \{Q'_1 \cup Q_2, Q'_2 \in A^1(Q_1)\} \cup \{Q_1 \cup Q_2, Q'_2 \in A^1(Q_2)\} \cup \{Q'_1 \cup Q'_2 Q'_1 \in A^1(Q_1)\} \cup \{Q'_1 \cup Q'_2 Q'_2 \in A^1(Q_2)\}.
\]
Movement of the object B:

Once the movement of a single proper part has been defined, moving the object partially or totally simply is the matter of moving in turn all the elements of \( P^o(B) \).

From the programmatic point of view, computation of all the transitions for a given relation \( R \) is performed as follows:

\[
\text{FOREACH } E \in P^o(B) \text{ DO}
\]

\[
\text{FOREACH } P_i \text{ proper part of } B \text{ element of } E \text{ DO}
\]

Compute the union \( Q \) of parts of \( A \) such that \( P_i \subseteq Q \)

\[
\text{FOREACH } \text{destination } D \in A_{\neq Q}(Q) \text{ DO}
\]

\( N_R \leftarrow M_R \), where \( M_R \) is the matrix for the relation \( R \)

Modify \( N_R \) according to the movement \( Q \rightarrow D \)

**DONE**

**IF** \( N_R \) is not a valid matrix

**apply consistency constraints to** \( N_R \)

**DONE**

"Modifying \( N_R \) according to the movement \( Q \rightarrow D^* \) consists in setting 0 and -0 in cells of the matrix \( N_R \). For example, if \( Q = \{ \omega \} \), \( A(Q) = \{ \omega, \partial \} \), and \( E = \partial L \) (section 3.1, movement of \( \partial L \) only), we will perform the following operations:

\[
N_{R_0}[O_L, Z^o] \leftarrow 0, N_{R_0}[O_L, Z^o] \leftarrow -0, N_{R_0}[\partial L, O_Z] \leftarrow -0
\]

for the first movement, and

\[
N_{R_0}[O_L, Z^o] \leftarrow 0, N_{R_0}[\partial L, O_Z] \leftarrow -0
\]

for the second one.

Consistency constraints depend of the objects we are working on.

Extended conceptual neighborhoods for line-zone relations

This section presents the application of the movement model to line-zone relations (defined by the 9-intersection model) in order to build the extended graph of conceptual neighborhoods. In the construction the line \( L \) is moved while the zone \( Z \) is still.

In the 9-intersection model, \( L \) has two proper parts: \( L^o \) and \( \partial L \).

For modeling the movement of \( L \), we need to perform in turn the movement of \( L^o \) while \( \partial L \) is still, the movement of \( \partial L \) while \( L^o \) is still, and finally the simultaneous movement of \( L^o \) and \( \partial L \).

As we are working with simple lines (lines having 2 boundaries), we need the number of cells such that \( N_R[O_L,i] = 0, i \in \{ Z^o, \partial Z, Z^o \} \) to be strictly less than 3. This constraint must be verified in all cases. If it is not verified, the transition must be rejected.

When \( \partial L \) is moved alone, we use consistency constraints that were used in the smooth transition model (equations 5, 6, and 7).

These three constraints act on the newly produced matrix \( N_R \). Constraint 5 does not act on \( O_L \); constraints 6 and 7 modify the position of \( L^o \) according to the new position of \( \partial L \).

When \( L^o \) is moved alone it is required to correct the position of \( O_L \) according to the new position of \( L^o \). The following consistency constraints are defined (where \( =_{M_R} \) tests equality in the matrix \( M_R \) while \( =_{\neq} \) tests equality in the newly constructed matrix \( N_R \)):

\[
O_L \cap Z^o = M_R = 0 \land O_L \cap Z^o = 0 \Rightarrow O_L \cap Z^o = 0 \land O_L \cap O_Z = -0
\]

(13)

This constraint specifies that if \( L^o \) moves completely from \( Z^o \) on \( O_Z \) and if there was an intersection between \( O_L \) and \( Z^o \), then \( O_L \) also moves completely from \( Z^o \) on \( O_Z \). Note that \( O_L \cap Z^o = M_R = 0 \Rightarrow O_L \cap Z^o = 0 \land O_L \cap O_Z = -0 \) (as all proper parts of the line are connected) and that \( L^o \cap Z^o = 0 \) specifies that all the line's interior has left \( Z^o \) (the destination \( O_Z \) is implied as \( \text{Adj}(Z^o) = \{ O_Z \} \)).

The constraint:

\[
O_L \cap Z^o = M_R = 0 \land O_L \cap Z^o = 0 \Rightarrow O_L \cap Z^o = 0 \land O_L \cap O_Z = -0
\]

(14)

is equivalent to the constraint 13 for \( Z^o \).

Finally, we add the constraint 5 which insures that the interior of the line is connected.

When \( L^o \) and \( \partial L \) are moved simultaneously, both sets of constraints should be applied in turn on matrices that correspond to non-existing relations. The experience shows however, that after the boundary corrective constraints have been applied, no new transition is obtained if interior corrective constraints are used.

As we are gaining many new transitions, a graphical representation is not readable. The graph is thus represented in tabular form in table 1 where target relations between parenthesis represent targets obtained by the smooth transitions model. As we will see in the next section, some of these transitions are not "atomic" and must be rejected. The targets of non-atomic transitions are written in bold.

Pruning non-atomic transitions

For many transitions in table 1 it is rather easy to find a geometrical interpretation of the line's movement (see for example figure 5). This is however not the case for all transitions, as for example \( R_3 \rightarrow R_{15} \). It actually appears that this transition cannot be performed atomically. This section describes the method for detecting and eliminating these non-atomic transitions. The discussion is based on the example of line-zone relations but can be adapted to any objects.

\( R_3 \) is obtained from \( R_3 \) if \( L^o \)’s sub-part that lays on \( O_Z \) (let’s call it \( L^o_{z_+} \)) moves in \( Z^o \) while \( \partial L^o_{z-} \) sub-part that lays in \( Z^- \) (\( L^o_{z-} \)) moves entirely on \( O_Z \). Due to the constraint defined in equation 14 the boundary of the lines is also required to move on \( O_Z \). An intuitive reason for the difficulty of interpretation of this transition is that it requires "less time" to leave \( O_Z \) than to leave \( Z^- \). In other words, when \( L^o_{z+} \) enters \( Z^o \), \( L^o_{z-} \) cannot have left entirely \( Z^- \), as depicted on figure 5. The transition \( R_3 \rightarrow R_{15} \) requires an intermediate step: it is not atomic.

A more formal explanation requires to take into account the dimensions of the parts that are sources of the movement. The definitions below apply in the case when a line is moving with respect to a zone; they can however be easily adapted to other objects.

Definition 4 (instantaneous, continuous movement)

A movement is said to be "instantaneous" if its source is \( O_Z \) and its destination is either \( Z^o \) or \( Z^- \).

A movement is said to be "continuous" if its source either is \( Z^o \) or \( Z^- \) and its destination is \( O_Z \).

Definition 5 (Atomic line's movement)

The movement of a line is said to be "atomic" if the movements of all the proper parts or sub-parts of the proper parts implied by the general movement are of same nature (all instantaneous or continuous).

Let’s take some examples from table 1:

- \( R_6 \rightarrow R_{12} \) is obtained by: \( \{ O_Z \} \rightarrow \{ O_L \} \).

As neither \( L^o \) nor \( \partial L \) appear in the destination, the sub-parts of \( L^o \) that were laying in \( Z^o \) and in \( Z^- \) did move on \( O_Z \). We therefore had two sub-movements: \( Z^o \rightarrow O_Z \) and \( Z^- \rightarrow O_Z \) which according to definition 4 are both continuous. The whole movement is therefore atomic (def. 5).
Table 1: Neighbors obtained by the movement model. The left column is the source relation, the right columns contain the names of the target relations. The first line are the targets obtained by moving line's boundary, the second line are targets obtained by moving line's interior, and the third line are additional targets obtained by simultaneous movements of the interior and of the boundary. Relations between parenthesis are those obtained by the STM. Relations written in bold font are to be rejected as they are not atomic (see text).

<table>
<thead>
<tr>
<th>Relation</th>
<th>Neighbors</th>
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<tbody>
<tr>
<td>$R_1$</td>
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<td></td>
<td>($R_5$), $R_{12}$</td>
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<td>$R_{13}$, $R_{14}$</td>
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<td>($R_{17}$), $R_{10}$</td>
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- $R_6 \rightarrow R_{18}$ is obtained by: $(^* \frac{2L}{S} \rightarrow ^{\phi \sigma})$.
  As $\sigma$ appears in the destination and not in the source, the movement to take into account is the partial movement of $\partial L$ from $Z'$ on $\partial Z'$. By definition 4, this movement is continuous, and as it is the only movement in the transition, the transition is atomic.

- $R_6 \rightarrow R_{15}$ is obtained by: $(\partial Z) \overset{L}{\rightarrow} \overset{^\phi}{^\sigma}$.
  Because of the definition of the adjacency on the zone object, this movement requires that the sub-part of $L$ that lays on $\partial Z$ moves in $Z'$ and that the sub-part that lays in $Z'$ moves on $\partial Z'$. The first sub-movement is instantaneous, while the second one is continuous. The transition $R_6 \rightarrow R_{15}$ is therefore non-atomic and must be rejected.

Practically, the test for deciding whether a transition is atomic or not will be performed as follows. First assume one proper part $P$ of the line is moving from the source $s_1 \ldots s_n$ on the destination $d_1 \ldots d_m$, where $s_i$ and $d_i$ are zone’s parts $\{s_i \ldots s_n \rightarrow \{d_i \ldots d_m \}$.

First determine what sub-movements are required for the realization of the whole movement of $P$. Then for each of these sub-movements, determine their nature (continuous or instantaneous). If all the sub-movements are of identical nature, accept the transition. If the two proper parts of the line are moving, then accept the transition if the sub-movements required by both whole movements of both proper parts are of identical nature.

It is important to notice that this test must be applied on proper parts that are actually moving and only on these. In other words, it must be applied before any consistency constraint was used for correcting the new matrix $N_P$. Otherwise, transitions like $R_{14} \rightarrow R_7$ would be rejected as $L''$ “jumps” over $\partial Z'$.

Once non-atomic transitions have been pruned, we obtain the extended graph of conceptual neighborhoods shown on figure 6. For readability, only the new transitions obtained by the movement model are depicted.

**Conclusion**

This section described a general method for building conceptual neighborhood graphs among topological relations. As an example, we did build the graph for line-zone relations. If other objects are considered, only consistency constraints and the pruning algorithm have to be adapted.

The graph we obtain for line-zone relations is oriented. As the movement model is an extension of the smooth transition model, we inherit all the asymmetric transitions $(R_1 \rightarrow R_7$ for example). Moreover, few new asymmetric transitions are produced by the new model $(R_6 \rightarrow \{R_7, R_8\}$ and $R_{10} \rightarrow \{R_7, R_8\}$). As for the STM, counterparts of asymmetric transitions are easily interpreted in terms of movement. The graph can therefore be considered as non-oriented.

**4 DISCUSSION AND PROSPECTIVE WORK**

This section shortly presents two applications of the conceptual neighborhood graphs based on the movement model presented above. First, it is however necessary to state the context of our work.

As stated in the introduction, we are working on a GIS query interface based on a graphical representation of spatial configurations (Szmurlo et al., 1998, Szmurlo and Gaio, 1998). This interface is hybrid, in the sense that spatial constraints are represented as a sketch while the types of the objects and the thematic constraints are expressed as expressions in natural language. Distance relations are partly expressed as graphics (to specify which objects are in relation) and partly in natural language (to specify the actual distance). In order to avoid the problem of image preprocessing and object recognition, our drawing tool is a constrained...
words, relations between only parts of the objects should be taken
into account. Let’s consider sketches (a), (b) and (c) from figure 7. All three correspond to different topological relations but all may express the “crossing” concept applied to different types of objects: a river crossing a town (rarely a town contains an entire river), a road (that begins in the town) crossing a town (and that goes away), and an avenue crossing a town. Conversely, even if sketches (d), (e) and (f) represent the same topological relations as sketches (a), (b) and (c), respectively, they do not correspond to a “crossing” but rather to “circumvent” (d)) and “go along” ((e) and (f)) configurations. The information that captures the “crossing” concept is that, at some moment, the line is near the zone’s boundary, then it goes trough the central part of the zone, and finally, it is again close the zone’s boundary, regardless of what happen to line’s boundary and the rest of line’s interior.

To be able to model concepts this way, and in order to have a generic model for spatial relations, we define a new set of topological regions for defining objects. For a zone we may need: the central interior, the peripheral interior, the intermediate interior, located between Z−′, and Z+′, the peripheral exterior, Z−, and the external exterior, Z+. These parts are mutually exclusive. By considering the 6×3 boolean matrix that defines all the possible intersection between the six new zone’s parts and the three "traditional" parts of the line, we define a new set of topological relations between a zone and a line. The new topological parts are shown figure 8. Such an extension results in many new relations. However, as we intend to model concepts locally, only those parts of the matrices that enter in the definition of the concept are to be considered.

In this context, the graph based on the movement model may be used for two purposes. Assume that the sketch is interpreted into a
given concept $C$ and that this interpretation is refused by the user. The the analyzer would perform movements of the parts that enter in the definition of $C$ in order to obtain new configurations. This is straightforward as the graph’s model is defined independently of the number of parts implied by the embedding of the object in the universe. Some of these new configurations may correspond to different concepts $C'$, other may still correspond to $C$ itself, and finally, some new configurations may correspond to no particular concept at all. In the first case, new propositions based on $C'$ will be done to the user. Once the user accepts the propositions of the analyzer, the system must generate the query that will be issued to the GIS. Furthermore, it must take into account the refused concept $C'$, that is that all the relations corresponding to $C'$ must be eliminated from the query construction process. Once again, the graph can be used to determine the set of these relations.

5 CONCLUSION

This paper presents an extension of the smooth transition model for building graphs of conceptual neighborhoods among binary topological relations. The new model, the so called movement model, is defined generically for any pair of objects and defines the movements of one object with respect to the second one. The example of the graph for line-zone relations defined by the 9-intersection is straightforward as the graph's model is defined independently of the given concept $C$ in order to obtain new configurations. This is straightforward as the graph’s model is defined independently of the number of parts implied by the embedding of the object in the universe. Some of these new configurations may correspond to different concepts $C'$, other may still correspond to $C$ itself, and finally, some new configurations may correspond to no particular concept at all. In the first case, new propositions based on $C'$ will be done to the user. Once the user accepts the propositions of the analyzer, the system must generate the query that will be issued to the GIS. Furthermore, it must take into account the refused concept $C'$, that is that all the relations corresponding to $C'$ must be eliminated from the query construction process. Once again, the graph can be used to determine the set of these relations.

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