A VORONOi-BASED PIVOT REPRESENTATION OF SPATIAL CONCEPTS AND ITS APPLICATION TO ROUTE DESCRIPTIONS EXPRESSED IN NATURAL LANGUAGE

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Abstract
Different representations of space are not in general equivalent. This point is clearly illustrated in research on the generation of sketches from route descriptions given in natural language: many linguistic expressions determine only partially a spatial situation. This article explores the role played by a pivot representation based on the Voronoi diagram. We study the use of this model in the context of the translation of verbal descriptions into sketches. We show how, by combining a linguistic analysis of a route description and the Voronoi model of space, one can construct a pivot representation that integrates both the spatial and linguistic aspects of a situation, We aso examine the use of the pivot representation within the framework of the automated generation of linguistic descriptions from geographical databases. The development of a pivot representation depends on the existence of a dictionary that renders explicit the equivalence between linguistic and spatial aspects of each situation. With the help of the Voronoi model, the basis for such a dictionary has already been established for spatial prepositions in English. Extensions to other linguistic elements are under study and appear to be achievable.

Key words
Route descriptions, spatial representations, Voronoi data model, natural language representations, linguistic analysis.

1. Introduction

The problem of developing computer programmes for constructing or enriching route descriptions, such as for pedestrians in an urban environment, is complex. Furthermore, although work has been done with robot navigation in artificial environments, and with road navigation, again a simpler environment, little attempt has been made to tackle the task of providing information to pedestrians in complex, realistic urban settings.

In order for such instructions to be useful, they must be provided in a form which is familiar to the client. This requires an understanding of the cognitive procedures which people use to navigate in complex environments. Many tourist information systems today provide a bird's eye map view containing the point of origin and the destination point and indicate the route on the map. Most humans, however, when asked to provide the means to guide someone from one point to another within a city, spontaneously provide verbal instructions. Sometimes a sketch may be used to help clarify the instructions. Furthermore, when instructions are given over a phone, there is little choice but to employ verbal means. Hence, in a fully functional and useful city guide system, the computer should be able to offer linguistic route descriptions and partial sketches as well as full map views, depending on the nature of the information request and the desires of the client.

The construction of linguistic descriptions, or their enrichment based on information about the environment, is itself a complex task. A great deal of knowledge about cognitive processes is required (how do people choose which elements of the environment to include in their descriptions? what kinds of strategies for path selection are employed, when many possible paths are possible? and so on), as well as knowledge about linguistic choice (what language forms do people typically use to express spatial information in route descriptions?) and knowledge about the role of sketches as an aid to such linguistic descriptions (what elements do people choose to represent on a sketch being used in combination with a linguistic description?). The task also requires an understanding of the problems involved when manipulating spatial data on a computer, especially when an existing database is to be used to help construct the linguistic description or sketch. Finally, means must be provided to carry out qualitative “spatial reasoning” and hence to permit information to be deduced within such complex environments.

This paper surveys the state of an existing multi-disciplinary project designed to address some of these issues. The work to date has been focussed on four related areas: (1) a cognitive based study of two corpus of textual route descriptions designed to identify the key strategies and choices used by humans when giving route directions; (2) the development of procedures necessary for the tranformation of a linguistic route description to a graphical visualisation; (3) the development of methods of performing qualitative spatial and spatio-temporal reasoning about the world; and (4) the study of the use of the Voronoi diagram as a bridging structure between geographic information and linguistic representations. We shall provide a brief overview of this work, then discuss the importance of a pivot representation, and finally show how the latter can be used in the context of our project.

2. The production of a route description

The project is based on the analysis of two corpus of texts collected by A. Gryl (1995). The first corpus deals with descriptions of journeys in a semi-urban context, that of a university campus. The corpus consists route descriptions acquired from 60 subjects asked to describe three journeys which together form a closed loop (from the railway station to Building A, from Building A to the library, and from the library back to the station). The second corpus collected consists of route descriptions provided by another 30 subjects, this time for a fully urban context, that of moving between two well known departement stores, one on the left bank and one on the right bank of the Seine in central Paris. In each setting, route descriptions in both directions were obtained, in order to test for differences resulting from the order in which landmarks were traversed.

From the two corpus of route descriptions, Gryl (1995) carried out an analysis of their linguistic content and the strategies employed by the subjects in choosing routes and landmarks within the descriptions. The analysis permitted the broad outlines of a strategy for the automated generation of route desctiptons to be determined, based on the most frequently used elements within the corpus of route descriptions. Hence, for example, it was noticed that landmarks were not preferentially tied to a particular direction, subjects tend to suggest the use of main traffic arteries, and they tend to limit the number of turns or decisions required by the listener to follow the trajectory. These and other results of the analysis led to a proposal for a computer implementation of the procedure in three steps:

The first, called “Where to go?“, consists of the construction of a representation of the route description according to a trip strategy. This step is divided into two phases, one serving to provide a global orientation, and the other for the creation of a path between the point of departure and the point of arrival, according to a variety of criteria.

The second, “By what means?“, consists of refining the representation produced by the first step according to a more precise strategy. During this step, the general descriptions are enriched via the introduction of landmarks that are usable by human beings. Moreover, the planned path is segmented into two types of elements: local descriptions and continuation paths. Local descriptions are attached to steps of the itinerary where a decision is to occur (change in orientation, continuation of the path in the presence of ambiguity, a decision to take with respect to some aspect of the environment); whereas continuation paths connect these local descriptions.

The third step, called “How to say it?“, consists of translating the preceding representation into natural language. This translation uses additional information from the database, including elements such that the shape of landmarks, their names, their sizes, their colors and their intrinsic orientations.

Each of these tasks is itself an entire area of research. To carry out this program correctly implies: linking the spatial relations expressed by prepositions and other linguistic structures with corresponding cartographic configurations (Freksa 1992, Ligozat 1993, Frank 1992, Gapp 1994, Oliver and Tsujii 1994; Edwards and Moulin 1995); analyzing linguistic expressions in terms of static descriptions, movement, etc. (Herskovits 1986, Talmy 1983); identifying linguistic markers that signal special conditions related to spatial concepts (Fraczak 1994); managing the temporal aspects of language (Allen 1984, Ligozat 1991); adjusting the processing requirements according to each natural language (Dorr and Voss 1993); and improving our understanding of the cognitive abstraction process that allows one to choose certain marks in a scene in order to obtain an appropriate verbal description (Gryl 1995, Kuipers 1978). Hence a full realisation of the task is unlikely over the short term. On the other hand, this paper presents a key element in the realisation of this programme. It is our belief that with the problem of linking the spatial relations expressed in linguistic structures on the one hand and cartographic configurations on the other solved, other parts of the task become easier and the whole program may be realisable.

3. From description to sketch

As has been indicated, a verbal route description is frequently associated with a sketch of the situation in order to facilitate comprehension and help with the memorisation. In order to study the processes used in each of the two modes of expression, we have undertaken the task of developing a system allowing the automatic translation of information in the linguistic mode to a graphical format (Fraczak 1995). This work is based on the first corpus of texts collected by Gryl (1995), that dealing with pedestrian routes on a university campus.

The effort to produce a visualisation of the linguistic description led to the observation that the two modes of expression are not equivalent. Indeed, while certain kinds of information are not represented explicitly in the linguistic description, the graphical mode requires their representation. Conversely, some verbal information cannot be expressed graphically. The imbalance consists therefore of either a lack of completeness in the linguistic representation as compared to the graphical representation, or the lack of certain elements in the graphical representation as compared to the linguistic representation. Here are examples of each of these situations:

- *incomplete linguistic information (not verbalised):*

You pass in front of the cafeteria.	(to the right or to the left?)
At the church, take the pedestrian path.	(where is the path compared to the location of the church?)

- *incomplete graphic information (not figured):*

You can't miss it.
It's simple.

We have developed a translation system based on three steps: (1) a linguistic analysis; (2) the elaboration of intermediate representations (semantic and conceptual); and (3) the generation of the sketch.

First of all, the route description is divided into sequences that are linked via connectors. This is necessary to encapsulate the information to be used for the graphical visualisation. For example, in the description fragment:

it is necessary to enter the station and then to take the pedestrian walkway

there are two sequences, it *is necessary to enter the station* and to *take* the pedestrian walkway, linked by the connector *and then*. Sequences are categorized into two types: sequences which include a prescription of action and sequences which are used to indicate landmarks. Furthermore, each sequence is analyzed via the use of a grammar of route descriptions, resulting in a semantic representation. Thus, in the example shown above, one will have a prescription of action (to enter) followed by a second prescription of action (to take a path).

Following this, the semantic representation is reformulated via a route prototype of the frame type, resulting in what is called a conceptual representation. This in turn becomes the basis for the generation of the sketch - a graphical symbolic language is used to represent the various types of landmarks, progression, and changes of direction. The graphical representation constitutes nothing more, at this point, but a formalized code for visualizing the conceptual representation.

4. The necessity of pivot representations

The procedures outlined above invite a certain number of questions with regards to possible generalization within a wider context:

1) Given a fragment of a route description and its conceptual representation, can one define the compatibility of these two descriptions, or determine if one of them satisfies the constraints set by the other?
2) Given a geographical database concerning the site where the displacement is to occur, and a linguistic description, a conceptual description, or a description in the form of a sketch, can one again define the compatibility of the description with the database? If so, can one then use the database to enrich or correct the description? Or to specify certain aspects of the description?
3) Is it possible to construct part of the geographical database or modify it in a substantial way, using linguistic descriptions, sketches, or mixed forms as a data source?.

On the other hand, the systems that we have just described are characterised by two important limitations:

Certain choices are arbitrary. In the case of converting the textual description to a sketch, when the verbal description is ambiguous (is the tennis court to the left or to the right?), an arbitrary choice is required for the visualisation. Although one could argue (Riesbeck 1980) that such choices do not affect the user (i.e. when following the route, the client will perceive immediately the error and correct it), the presence of such arbitrary choices is not totally satisfactory. One would like to have a representation in which one is not forced to make such a choice or where the ambiguity of the choice is clearly marked.

The absence of true spatial semantics. The elements used for the representation are constrained only by the characteristics belonging to the linguistic level on the one hand, and to the graphical level of the other. The problem of the comparison of these elements with data representing the external world is not addressed. This is even more critical for the generation of route descriptions, where (a small but appropriate subset of) the spatial relations between elements in the database need to be extracted directly and converted into linguistic form.

Based on these observations, we suggest that a pivot representation is required. A pivot representation would serve to anchor the individual representations which are specific to each mode: graphical, linguistic and database. The pivot representation would consist of a structure which supports all three modes (and might be extended to support other modes as well). Most current studies seek to establish links between two of the three types of representation, but none presently permit a representation covering all three. Thus, for example, most spatial databases permit good management of spatial relations only in the presence of intersections between objects. The extension of these data structures to the representation of proximity relationships must exploit additional methods (fuzzy set theory, for example), while the shapes of objects are characterized by still another mechanism. Hence a link is possible between proximity relationships expressed in natural language and objects in the database, but a visual representation of these relationships, in the form of a sketch for example, must rely on other techniques.

5. The Voronoi model

Recent work suggests that the Voronoi model of space may provide the solution to the problem of a common representation in support of all three modes. In order to understand the reasons why, we shall provide a brief description of this model.

The Voronoi model of space (Okabe, Boots and Sugihara 1991) is based on the processing of the whole space. Each elementary map object (a point or a line segment for instance) is embedded in a tile (also called a Voronoi region) which is the region of space closest to the given object than any other object in the space. Voronoi regions can be determined for any arbitrary shape. They are commonly generated around points and line segments and recent work has extended them to curves and faces. The set of Voronoi regions for a set of objects in space is called the Voronoi diagram for the space and objects. It is also called **a** Dirichlet tesselation and the Voronoi regions are atematively called Thiessen polygons. If the existence of a Voronoi boundary between two given objects can be established, then these objects are said to be neighbours, and we can say that they are adjacent. If the adjacency relations are represented by **a** line segment connecting the objects, then the set of all such line segments will form a Delaunay triangulation (for a set of points), called the dual of the Voronoi diagram. We call a *Voronoi model of space* the set of objects (half-lines and points) in two dimensional space (for the time being), their associated Voronoi regions and the dual which contains the information on adjacencies. Objects are specified as collections of half-lines and points. We use the term half-line to denote a side of a line or, alternatively, a line and an orientation. All lines are composed of pairs of half-lines, although it is conceivable that a single half-line might be modelled in some circumstances.

The Voronoi' model differs from the more commonly used raster and vector models in many fundamental ways. Both raster and vector models are coordinate-based models or fully metric models of space (although they use different metrics). The Voronoi model is not a fully metric model of space in the sense that coordinates are not needed to determine adjacency relationships (although they are used in the computer implementation of the model). The Voronoi model of space allows definitions of neighbours which are purely based on topological information in a direct and unambiguous way. The Voronoi model of space is also fundamentally dynamic since no object may move without several other objects knowing it has done so. Object motion can be defined in terms of topological changes (changes of adjacency relations between objects) and does not need to be expressed in terms of coordinate change. The Voronoi model is hierarchical in the sense that space is nested into increasing levels of detail, each level of which is embedded in the previous level. Object and space are intimately connected. The nested and tiled nature of Voronoi space allows us to effectively remove any piece of a map and replace it with a simplified (i.e. generalized) version of the object at a lower level of detail. This is analogous to the nominalization process in natural language.

A Voronoi' server has been developed by Gold (Gold 1994). It consists of a library of functions that can be used to create and to manipulate Voronoi diagrams composed of line segments and points and to make the link between these diagrams and a dataoase. Some of the functions accessible to the user include operators for the construction of the Voronoi diagram of an arbitrary collection of line segments and points (SetFrame, AddPoint, MovePoint, AddLine, JoinPoints, DeleteObject, etc.). Other functions allow one to construct queries (NearestObject, Neighbours, Trace, Clip, BufferZone, PolygonShade, etc). Furthermore, the data structure used is fundamentally dynamic, thus allowing the modeling of events over time as well as in space. Different application projects are under development, most of which are related to cartographic applications for GIS.

Edwards and Moulin (1995) demonstrated how the Voronoi model could be used as a computer simulation of a mental model in order to represent the different spatial relationships such as one finds in prepositions in English. This article pointed out the existence of a unique correspondence between each spatial preposition and a set of configurations of the topology of adjacency links within the Voronoi model. For example, Figure 1 shows the topology configuration which corresponds to the concept “between”. In fact, because the Voronoi model gives meaning to the different proximity relationships without requiring contact between objects (only contact between their Voronoi zones is required), the Voronoi model allows one to represent directly the totality of spatial relationships expressed in natural language. Furthermore, the notion of object contact, in the Voronoi model, has a preferential status compared to other relationships, because it corresponds to a particular kind of adjacency relationship between objects. Thirdly, overlapping relationships (between segments, between surfaces) are also part of the Voronoi model. Finally, it is possible to determine a gradation in the topological relationships of proximity represented by the Voronoi model, hence allowing a simple means of representing ambiguities and fuzzy elements in the categorization of different relationships. Thus the Voronoi model allows the representation of the full range of spatial relationships expressed in natural language.

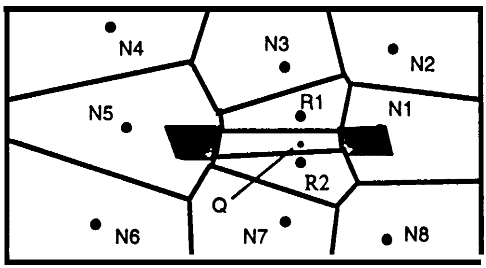

Figure 1 Situation representing the preposition "between" (Q is "between" R1 and R2 because its Voronoi zone is adjacent to the Voronoizones of R1and R2). Q is "Directly between" Rl and R2 if it also has both N1and N2 as neighbours.

We have already noted that shape descriptions must exploit representational mechanisms other than those which exist within database structures. Without entering into the details (and exceeding the reach of this article), it is pertinent to note that a mechanism exists within the Voronoi model which allows one to manipulate a concept of shape. This mechanism is the geometric skeleton of an object (also known as the medial axis transform). The geometric skeleton consists of the internal boundaries of Voronoi zones of an object (it is necessary also to add the concept of radius or minimal distance between the boundary and its generator objects in order to reconstitute the skeleton according to its formal definition (Ogniewicz 1993)). Thus, the skeleton is simply another way of speaking about adjacency relationships between Voronoi regions. Using this concept, it is possible to categorize shapes, to simplify them (Ogniewicz 1993), to reconstruct them from a incomplete information (Blum and Nagel 1978) and many others operations, Furthermore, although the link between these visual properties and corresponding linguistic expressions has not been explored much, preliminary work confirms the existence of such links. Furthermore, many properties of the skeleton (categorization, generalization, reconstitution) are precisely those that one finds in the linguistic expression of shape (Landau and Jackendoff 1993).

Thus, the Voronoi model provides a spatial database structure that manages both relationships of contact (intersection, overlap, tangential contact, etc.) and relationships of proximity (close, far, between, beside, etc.). Furthermore, the model allows **a** direct characterization of the shapes of objects through their geometrical skeletons. The Voronoi model therefore contains a representation of objects in space which allows both an analysis of their visual and graphic elements, their linguistic representation and their manipulation within a spatial database structure. Hence this model can serve as an intermediate representation for the development of links between these three areas.

The use of the Voronoi model as a pivot representation addresses the second problem outlined in the previous section - that of providing a true spatial semantics which can be anchored in the real world. In so doing, a (partial) solution is also applied to the first problem - that of handling ambiguities in the linguistic representations. Indeed, the pivot level allows us to avoid, in many cases, making arbitrary choices in the visualisation. For example, in the case of the tennis court, the use of the Voronoi model at the pivot level allows us to represent the region associated with the expression pass the tennis court (i.e. the region through which one passes) rather than the tennis court itself (which can then be found to the right or to the left by the pedestrian when following the route in reality).

6. Construction of pivot representations based on the Voronoi diagram

In the case of the problem of sketch generation, we will assume that a linguistic analysis has led to a preliminary identification of the spatial context. Studies by Fraczak and Ligozat described in the third section of this article lead currently to a such result (Fraczak 1995). Thus, as we have indicated earlier, route descriptions can be decomposed into **a** series of sequences and connectors between these sequences. For example, consider a part of the description quoted by Fraczak (1995):

> It is necessary to leave the station', to take the pedestrial walkway[2], to descend the walkway[3], and one arrives then at the entrance to the university[4].

This text is composed of a series of four sequences, separated by implicit or explicit connectors (in the text, sequences are indexed by a number). Furthermore, each sequence which is composed of a prescription of action uses a certain number of landmarks. For example, the first sequence corresponds to a trip between the interior and the exterior of the station (a particular type of landmark). The second sequence refers to a trip between the exterior of the station and the interior of a pedestrian walkway. Thus each sequence implies **a** limited spatial context.

The linguistic analysis of this description leads to the characterisation of the first sequence, as **a** prescription of action (“to exit”) corresponding to the verb class “to progress” with respect to an object named “station”. Additional processing of the linguistic aspects of the text then leads to the identification of other landmarks and qualifiers, resulting in the construction of a more complete conceptual representation. In the approach outlined earlier, the sketch itself is simply the graph formalisation of the information that is found in the conceptual representation. We propose here to enrich this formalisation by combining the linguistic and spatial aspects via a pivot representation, Two process are possible: the first presupposes the availability of a spatial database; the other, more limited, does not.

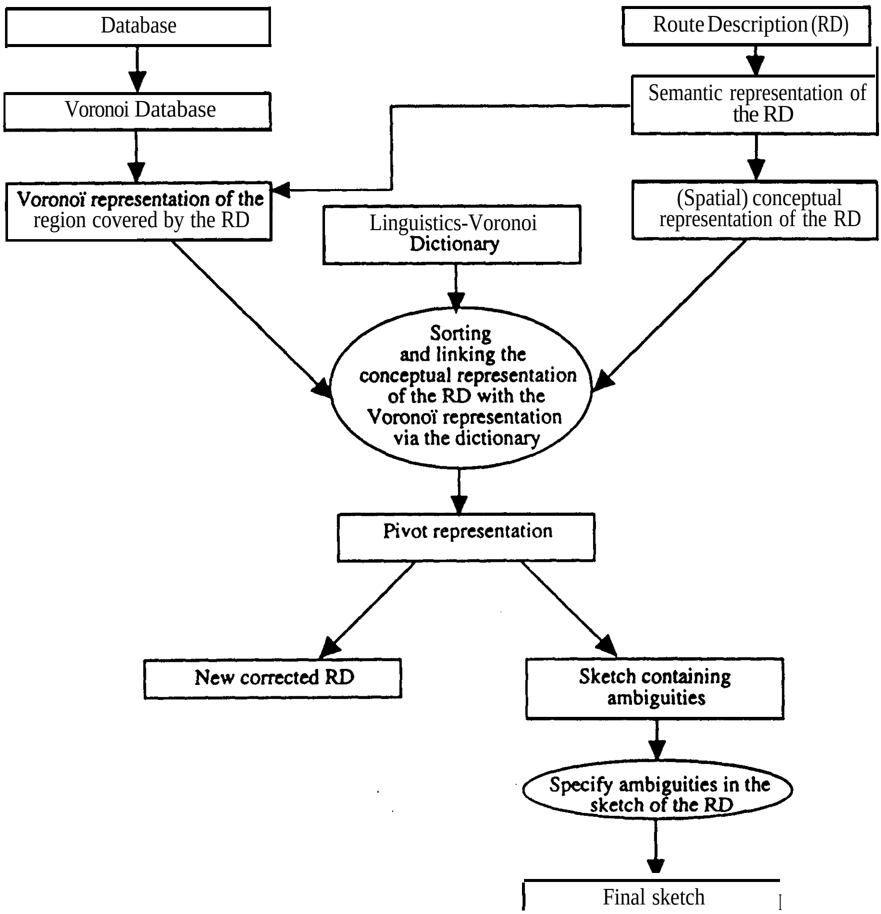

*Figure 3 Flow diagram showing the processing of route descriptions and the construction of a pivot representation when **a database is available.***

We present first the approach which relies on the existence of a spatial database. Figure 2 presents the proposed solution. The linguistic processing schema of the route description (RD) is represented by the box at the top right. At this stage, the spatial relations and other spatial information are extracted from the linguistic description. At the top left, the database (or a part of it) is transferred into the Voronoi data structure. This step corresponds to the explicit determination of the spatial relations and other spatial information present in the database. Following this, with the help of the semantic representation, and especially its segmentation into distinct sequences, the Voronoi reaion directly pertinent to a particular linguistic sequence is selected, Thus, to give a concrete example, in the case or the sequence concerned with exiting the station, Figure 3a would correspond to the original database, and Figure 3b to the Voronoi version of the database.

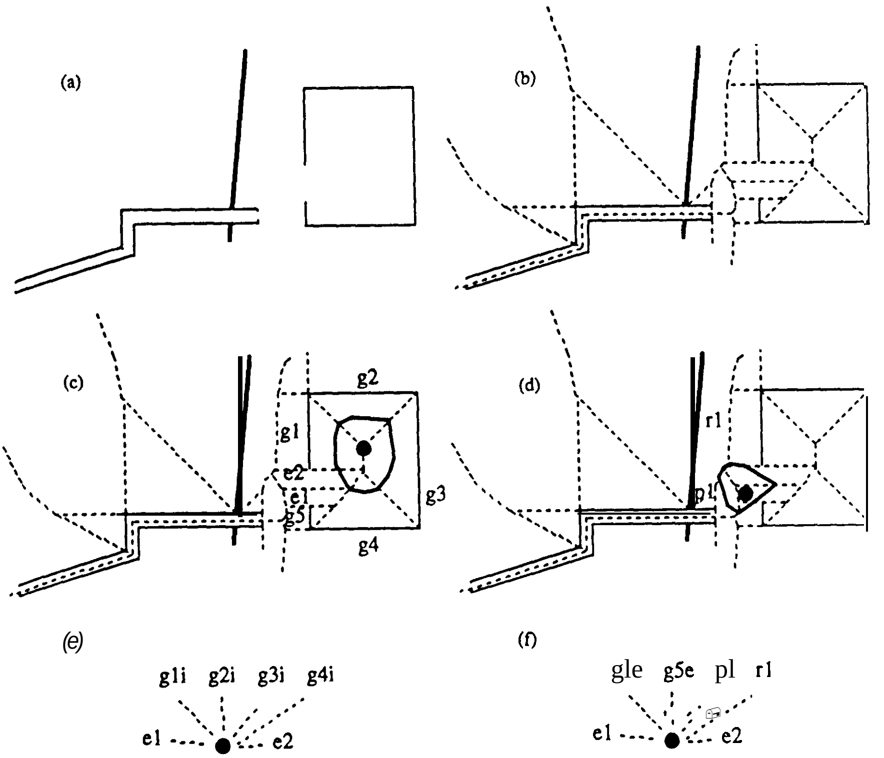

Figure 3 The process of extracting spatial *relations from* a *geographic database. (a) the* original database *containing* the *station, section of railway and pedestrian walkway; (b)* the *database after conversion to its Voronoi form; (c)* the *situation corresponding to the location of a marker "inside" the station (the letters identify, sequentially pertinent geometric* objects, g *for gare or station, e for entryway, p for pedestrian walkway; r for railway); (d) the situation corresponding to the location of a marker "outside' the station (and ready to move into the walkway); (e) the topology of adjacencies corresponding to the marker "inside' the station (the extension* i indicates that these are interior half-lines *or walk); (f) the topology corresponding to the marker 'outside' the station (the extension e indicates that these are exterior half-lines or walls).*

The next step consists of extracting the elements of the route description which correspond to the elements to be found in the Voronoi database and of linking these to the conceptual representation built from the relevant linguistic sequence of the route description. Figure 3a represents the relevant object (the station) and Figure 3b its Voronoi zones. Figure 3c shows the situation which corresponds to the inside of the station (state of departure for the action "exit") and Figure 3d presents the situation for the exterior of the station (state of arrival for the action "exit"). In both cases, a marker element has to be introduced in the scene so as to represent the observer in the situation. Figure 3e indicates a possible path between the two states, insuring that the indicated route is possible. It should be noted that what is important in these figures is not the exact position of the marker with respect to the Voronoi zones, but rather the topology of adjacency relations between the marker and the relevant objects (e.g. the inside walls of the station). Thus, given the situation shown in Figure 3b, it is possible to search for and find the situations shown in Figures 3c and 3d, provided the linguistic sequence has been transformed into a Voronoi topology. This can be done by means of a dictionary, giving, for each linguistic element, one or several characteristic Voronoi' topologies. The basic concept of such a dictionary, at least for spatial prepositions, has already been established (Edwards and Moulin 1995). All spatial prepositions appear to be supported by this approach. Hence the pivot representation consists of the topological representation of the set of (Voronoi) adjacencies present in the scene and necessary to support or generate the linguistic descriptions, combined with the dictionary which allows linguistic structures to be built out of such topologies.

Once this step is crossed, it becomes possible to determine any errors which might be found in the existing route description, to enrich the route description with other relevant information, to compare different route descriptions, or to produce either a complete drawing of the situation and/or a sketch that presents only the information found directly to the RD (e.g. by explicitly rendering any ambiguities).

The second approach corresponds to the situation where no database is available. In this case, one may have several descriptions of the same region, but no direct way to verify their veracity. The process is similar, however, although more limited in its conclusions. The different route descriptions must be analyzed according to the linguistic steps described above. Then, in combination with the dictionary, it will be necessary to construct two pivot representations giving the spatial topology, each deduced from its own RD. Following this, it will be necessary to combine these two representations into a single representation, provided common landmarks have been identified. Here, the conceptual representation of each RD will be underdetermined to some extent, and the construction of the pivot representation is more problematical than in the first approach to the problem. Nevertheless, once a pivot representation has been obtained, the remaining steps are very similar to those described when a database is present.

Finally, the Voronoi model is also usable at each step of the process described earlier for the production of route descriptions. On the one hand, if the original database, from which the global orientation and the initial path are determined, is a Voronoi database, adjacency relations between the different elements of the region are already explicit, facilitating the initial choice. Secondly, the choice of the content of each local description can also be determined by the spatial relations present in the Voronoi representation. The result of the first two steps will be a complete path expressed via a topology (or network), segmented into a series of continuation paths and interrupted by local descriptions. With the help of the dictionary described above, the translation of the complete path into a linguistic description will be possible via an inverse, but similar, process, to that used for the analysis of the route descriptions. Thus, a pivot representation of the RD can be built and exploited for the production of the final RD. Furthermore, the cognitive segmentation of the path will be subdivided again so as to create a text having a structure that is close to that proposed by Fraczak (1995) that is, a collection of sequences and connectors, the former composed of prescriptions of action (corresponding to continuation paths) and the latter of landmark descriptions (corresponding to local descriptions). The final production of the text will therefore be based on **a** conceptual description of local descriptions and continuation paths which will be converted to text using AI and linguistic principles (G ryl 1995).

The approach described in the preceding pages has not yet been implemented, although many of the pieces exist in prototypical form. In particular, Gryl (1995) has developed a formal set of specifications for the different modules of code which must be developed. These specifications, however, embrace many conceptual difficulties, not all of which have been outlined in this paper (some are purely linguistic in nature). Ongoing work consists of refining these specifications by examining the conceptual issues and experimenting with small prototypes in this and related projects (e.g. Edwards and Moulin 1995).

One of the conceptual issues which has not been addressed yet is that of hierarchy of detail. It is known that the Voronoi model supports different levels of detail (Edwards 1993), but this aspect has not yet been exploited in the concept of pivot representations. The issue of hierarchy of detail is closely tied to the issue of ambiguity, because that which is ambiguous at one level of detail may be well specified at a different level of detail.

7. Conclusion

We have seen how a linguistic analysis of a route description, combined with the Voronoi model of space, can be used to construct a pivot representation that links the spatial and linguistic aspects of a scene. We have shown how this representation can serve as a basis for the comparison between different route descriptions and for the transformation of the former into graphical forms. The process depends on the existence of a dictionary that renders explicit the equivalence between the linguistic and spatial aspects with the help of the Voronoi model of space. The basis for such a dictionary has already been established for all spatial prepositions in English.

We have illustrated the use of this pivot language for the particular example of the translation of verbal route descriptions into a sketch. We have equally suggested how the pivot level could be used in the context of the automated generation of textual route descriptions from a geographical database from a cognitive perspective (a central constraint being that the descriptions obtained must be intelligable and memorisable by human clients). Furthermore, the pivot representation is useful independently of the order in which elements are introduced into the process. Thus the pivot level constitutes a general tool for applications which need to combine the graphical and linguistic aspects of space It should be relevant in other situations of a similar nature.

Acknowledgements
Authors Edwards and Gold would like to thank the Association des industries forestières du Quebec (AIFQ) and the Canadian Natural Sciences and Engineering Research Cound (NSERC) for their financial support of this work by means of the establishment of the industrial Chair in Geomatics applied to forestry.

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