A Visibility and Spatial Constraint-based Approach for Geopositioning

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Abstract. Over the past decade, automated systems dedicated to geopositioning have been the object of considerable development. Despite the success of these systems for many applications, they cannot be directly applied to qualitative descriptions of space. The research presented in this paper introduces a visibility and constraint-based approach whose objective is to locate an observer from the verbal description of his/her surroundings. The geopositioning process is formally supported by a constraint-satisfaction algorithm. Preliminary experiments are applied to the description of environmental scenes.

Key words: Landscape perception, place descriptions, scene-finding approach, geopositioning.

1 Introduction

Geopositioning is a process whose objective is to relate a geographic location to a given entity, activity or person. This is supported by qualitative references to locations we employ in everyday discourse, *e.g.* place-names, and quantitative representations used in many activities based on coordinates-based navigation. Early geopositioning systems have been widely applied to quantitative models and geometrical representations of space. Despite the interest of these approaches for cartographical applications, they do not completely reflect the way a human perceives and describes his/her environment since he/she preferably stores and processes qualitative information. This is particularly relevant for natural environments since they do not have well-defined emerging structures similar to those present in an urban environment. Perception encompasses cognitive principles that favor memorization of the main properties of an environment, and potentially communication of these properties to an external addressee using natural language [1,2]. These descriptions are essentially qualitative and based on common sense, *i.e.*, intuitive concepts we daily manipulate to interact with our environment [3,4,5].

While the interpretation of spatial relations for the location of entities has long been studied, they have been hardly considered for the geopositioning of an observer perceiving his environment. The objective of the research presented in this paper consists in developing a model suitable with perception and spatial cognition, but also appropriated for the processing of quantitative spatial data. We consider the case of an observer located at a fixed vantage in a natural landscape, perceiving his/her 360° surroundings, and who is asked to provide a description of his environment to an external addressee. The description of such an environment underlines the salient entities of space, the spatial relations between them, and the structural properties of the environment. Entities are identified according to a semantic categorization, their proximity and orientation with respect to the observer [6]. The research presented in this paper extends this modeling approach by identifying the possible locations of the observer from the interpretation of the description of his surroundings. It is supported by a visibility and constraint-based approach. This provides a support for search and rescue approaches by bridging the gap between a qualitative map resulting from the direct perception of a scene, and a quantitative representation of the environment given by a GIS database.

The remainder of the paper is organized as follows. Section 2 presents the modeling background of the approach and a conceptual representation of an environmental scene. Section 3 introduces the context of this research and develops the modeling approach, based on the concept of visibility of salient entities and the interpretation of spatial relations as spatial constraints. Lastly, Section 4 draws the conclusions and outlines further work.

2 Modeling background

In a previous work, we have introduced a structural model of a scene generated from the interpretation of a verbal description. It identifies the salient entities, spatial relations between them, and spatial constructs of the landscape [6]. The spatial description is schematized by a representation that constitutes a modeling support for the study of environmental scenes, *i.e.*, 360° scenes perceived by an observer from a fixed vantage viewpoint. The perception of an environment is closely associated to a cognitive organization that reflects different levels of perception [7]. Since humans tend to structure space using distance and bodily directions, an environmental scene is structured by four proximity spaces determined by their distance from the observer, and a directional cone-based partition [8] whose number can vary from two (front/back or right/left) to four (front, back, right and left).

Let us consider an example of scene description given by an observer to a distant addressee who is asked to consider the described environment: " I am on a footpath that runs along a castle and a pond. In front of me, there is a little valley with the castle on the right of it and at the horizon, I can distinguish a mountain range. On my right is the farm of the castle. Behind me, there is the pond with a meadow behind, and a forest far away ". In order to promote communication and cooperation, the observer contribution should be informative enough [9]. We assume that the resulting scene description can result from a preliminary complex dialogue between the observer and the addressee for the settlement of inconsistencies and vagueness problems. In order to keep the relevant information, the description is first parsed and semi-automatically filtered by the Tinky parser [10]. Co-references are identified and resolved, and the description is modeled as a set of triplets u_i such as $u_i = [e_j, r_k, e_l]$ with $e_j, e_l \in \mathcal{E}$ the set of entities of an environmental scene, and $r_k \in \mathcal{R}$ the set of spatial relations. Distance and directional relations are interpreted with the use of an application ontology, and the identified entities are associated to one-to-many proximity spaces and directional cones. No matter the nature, prominence or familiarity of the considered objects, the spatial relations are interpreted in order to favor their relative ordering.

The resulting conceptual map of Figure 1 illustrates the spatial structure, diversity and relative ordering of the entities. Such a model qualifies and characterizes natural landscapes, and provides a framework for the analysis of the properties of the verbal descriptions made by different observers, and cross-comparisons of different landscape descriptions. However, the salient entities of the scene are not always clearly revealed. This has motivated the integration of salience scores, supported by a mutual reinforcement algorithm. It reflects the particularities of the entities that emerge from a scene description such as their linguistic properties, *i.e.*, the richness of information associated to each term, and their structural characteristics, *i.e.*, the degree of spatial isolation [11].

3 Geopositioning approach

Recent years have witnessed significant geopositioning developments, particularly when locations are not available using global positioning systems. This has been applied to search-and-rescue operations where the location of a human (usually lost) should be retrieved. The ability of lost persons to precisely describe their perceived environment is essential to a successful identification of their location. The way people and particularly children behave and model their environment has been studied by cognitive studies, while cognitive distortions and reasons for retrieval failures have been qualified [12]. Preliminary experiments have explored the potential of GIS for the management of search teams [13], or the behavior of a lost person regarding her initial displacement plans, goals and own abilities [14]. However, GIS have not been used to the best of our knowledge for geopositioning an observer from a qualitative description and interpretation of his environment.

The description of the surroundings of the lost person is used as the only input of our approach. No assertion is made on their background, will, route, the reason why they planned the excursion, etc. The methodology used for the search of the observer results from the analysis of the verbal description. This is based on the interpretation of the entities and landmarks identified in the description, the spatial structure emerging from the proximity spaces that illustrate a relative ordering between the entities, and direction relations between the entities.

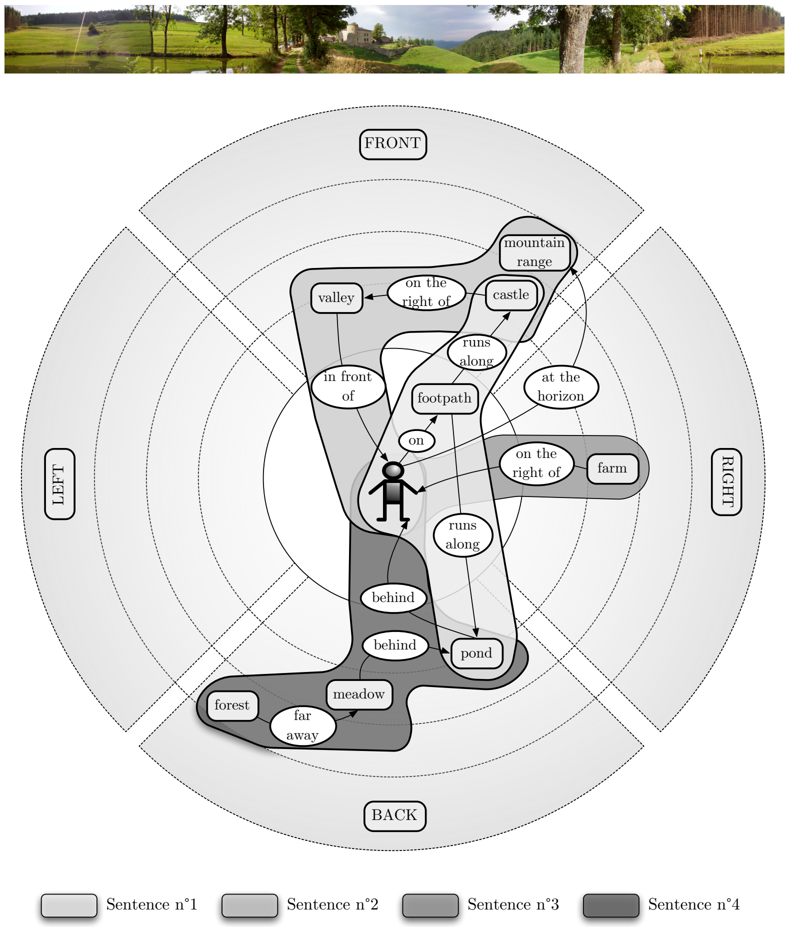

Fig. 1. Conceptual map of a scene [6]

The geopositioning approach searches for the possible locations of the observer, and is applied as follows:

1. For each entity identified by the observer, computation of the viewsheds *i.e.*, places for which each quoted entity can be perceived by the observer.
2. Interpretation of the direction relations derived from the directional cones and identification of a new set of candidate solutions for the observer location.
3. Interpretation of the distance relations derived from the proximity spaces and identification of a new set of candidate solutions for the observer location.

4. Interpretation of the direction relations given relatively to entities, and identification of a new set of candidate solutions for the observer location.

3.1 Visibility-based approach

Viewshed computation and analysis have long been applied in landscape and urban studies [15,16,17]. The main principle of a viewshed analysis is commonly determined by defining one location as the viewing point, and then calculating the line-of-sight to every other point within the region of interest. When the surface rises above the line of sight the target is out of sight, otherwise it is considered as in-sight [18,19]. The range of application is relatively large, from architectural studies where visibility represents a qualitative parameter for a site selection to minimize or maximize [20], to the distribution of forest-fire observation towers in natural environments [21].

The modeling approach should identify the possible locations of the entities quoted in the description. Let us assume that the described entities are directly visible from the fixed viewpoint of the observer. The visibility-based approach mainly focusses on the area from which the location of the entities can be viewed, as opposed to the visible area that is not equivalent because the height of the object at the viewing point may be different from the height of the viewed object [16]. Our objective is not to precisely locate the observer but rather the area the observer is supposed to be located at. Without loss of generality, we consider as equivalent the regions seen from a given entity and the ones visible from the observer.

Let us introduce the formal representation of the visibility-based approach. Let $\mathcal{E}$ be the set of entities e_i identified in a verbal description D, $\mathcal{S}$ denotes the ordered set of salient entities $e_i \in \mathcal{E}$, *i.e.*, $\mathcal{S} = [e_1, e_2, \ldots, e_n]$ and n denotes the cardinality of set $\mathcal{S}$. Let $\mathcal{B}$ be the set of objects of a GIS database considered as the repository of the region of interest. These objects and the relations materialized in this GIS database are organized into a lattice of classes and sub-classes, that result from a classification provided by the French Institut Géographique National (Fig. 2).

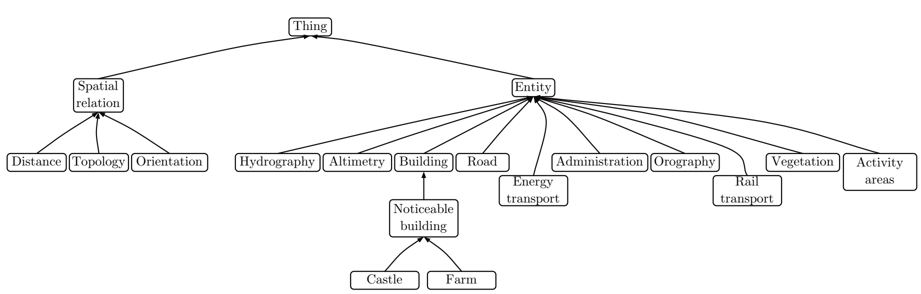

Fig. 2. Top-level concepts of the application taxonomy

Let $\mathcal{C}$ be the set of classes of the GIS database. The function f_{class} that associates the class $c \in \mathcal{C}$ to an object $b_j \in \mathcal{B}$ is given by

$$\begin{aligned} f_{class} : \mathcal{B} &\to \mathcal{C} \\ b_j &\mapsto c. \end{aligned} \tag{1}$$

Similarly, the function g_{class} that associates the class $c \in \mathcal{C}$ to an entity $e_i \in \mathcal{S}$ is given by

$$\begin{aligned} g_{class} : \mathcal{S} &\to \mathcal{C} \\ e_i &\mapsto c. \end{aligned} \tag{2}$$

Let $e_i \in \mathcal{S}$ a salient entity of the verbal description. Since entity e_i is visible by the observer, the visibility-based approach should select all objects b_j of the database that correspond to the class of objects identified in the description as all could potentially be perceived by the observer. Let $\mathcal{R}$ denote the set of m objects $b_j \in \mathcal{B}$ whose class fits that of entity e_i, *i.e.*, $g_{class}(b_j) = f_{class}(e_i)$, and $i \in [0, \ldots, m]$, $j \in [0, \ldots, n]$.

Let v be the function dedicated to the visibility computation. Let t be a digital terrain model, *i.e.* a triangulated irregular network that describes the topography of the region of interest. Given an object b_j located on terrain t, the viewshed of b_j is the set of points p of t from which b_j is visible. We consider that two points are defined as being visible to each other if a straight line can be drawn between the points without intersecting any part of the terrain surface between them, *i.e.*, $v(b_j, t) = \{ \text{ p} \in \text{t} \ / \ [b_j, \text{ p}] \cap \text{t} = \emptyset \ \}$. Let $h_{vis}(e_i)$ be the function that corresponds to the set of areas from which objects b_j, $j \in [1, \ldots, m]$ of a similar class than entity e_i are visible. Then, $h_{vis}(e_i) = \{v(b_1, t), \ldots, v(b_m, t)\}$.

Let S_{vis} be a function that computes the possible locations of the observer that result from the visibility-based approach. S_{vis} is defined by the intersection of the different viewsheds associated to each salient entity, *i.e.*, $\mathbf{S}_{vis} = \bigcap\{h_{vis}(e_i)\}$, where $i \in [1, \ldots, n]$. It is worth noting that the salience-based approach enables to consider only the most salient entities rather than considering all of them. Afterwards, we shall however take into account all entities.

Let us consider the example of description " I am on a *footpath* that runs along a *castle* and a *pond*. In front of me, there is a little *valley* with the *castle* on the right of it " and the resulting ordered set of salient entities $\mathcal{S}$={"castle", "footpath", "pond", "valley"}. Firstly, the m objects b_j of the database whose class is "castle" are selected and each viewshed $v(b_j, t)$ is computed. If object "castle" is the one considered, a solution for the possible location region of the observer is given by the set of viewsheds of b_j's, *i.e.* $h_{vis}(castle) = \{v(b_1, t), \ldots, v(b_m, t)\}$. The same method is applied to objects "footpath", "pond" and "valley", and the visibility-based solution is provided by the intersection of the viewsheds associated to each salient entity, *i.e.*, $\mathbf{S}_{vis} = \{h_{vis}(\text{``}castle'') \cap h_{vis}(\text{``}footpath'') \cap h_{vis}(\text{``}pond'') \cap h_{vis}(\text{``}valley'')\}$. The candidate objects are those that can be perceived directly from the area given by the visibility-based solution, *i.e.*, $\{b_j, c_j, d_j, e_j$ such as $b_j \in \text{``}castle'', c_j \in \text{``}footpath'', d_j \in \text{``}pond'', e_j \in \text{``}valley'' \ and \ \bigcap(h_{vis}(b_j), h_{vis}(c_j), h_{vis}(d_j), h_{vis}(e_j)) \neq \emptyset\}$.

The visibility-based approach identifies the possible location areas where the observer can be located. Figure 3 summarizes the principle of this approach. This first step also identifies a set of physical objects of the environment that could potentially be observed from the location regions $\mathbf{S}_{vis}$. This preliminary filtering of the solution area will be refined in the following sub-sections by the interpretation of spatial relations between these objects and illustrated by the proximity spaces and directional cones.

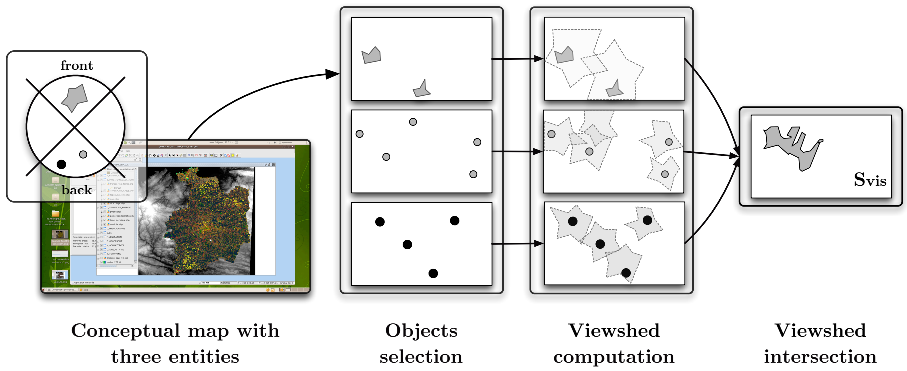

Fig. 3. Visibility principle

3.2 Spatial relations as spatial constraints

Spatial relations are interpreted as spatial constraints that refine the possible locations of the observer. These spatial constraints are derived from the interpretation of linguistic expressions, and supported by the use of directional cones and proximity spaces of the conceptual map. This can be considered as a specific application of declarative modeling that is commonly applied to the automatic generation of an environment that corresponds to some linguistic descriptions. In particular, text-to-scene modeling has been used in many applications such as architectural design [22], and for the generation of virtual urban landscapes and animated scenes from road accident reports [23]. These modeling approaches are based on the interpretation of spatial constraints and semantic knowledge [24]. This is equivalent to a constraint satisfaction problem applied to the linguistic relations identified in an environment description [25]. A constraint-solver algorithm analyses the coherence or incoherence of the linguistic description in order to derive a possible representation of the scene.

The interpretation of the spatial relations quoted in the description is supported by the directional cones and proximity spaces that structure the conceptual map (Fig. 1). The principle consists in finding the limits of the location of the observer for which:

– The entity locations in the directional cones fulfill the linguistic description properties (Cases 1 and 2).
– Distance relations given relatively to the observer are geometrically interpreted and supported by the use of proximity spaces (Case 3).
– Relative direction relations between two entities are geometrically interpreted (Case 4).

Case 1. Entities in opposite directional cones Let us consider two entities located into two opposite directional cones (front/back or right/left), *i.e.*, entities related to the observer by two opposite direction relations. The algorithm identifies the possible locations of the observer by computing the limits where object B is in front of the observer and object A is behind him, with a space segmented by two straight lines t_A and t_B that define the four directional cones, *i.e.* front, back and right, left. Objects A and B of the database are fixed, and the principle illustrated by Figure 4 consists in identifying the limits of the solution that satisfies the directional constraints by moving the directional cones along the whole boundary of object B. This generates a relative displacement of object A while retaining its location in the back cone, and object B in the front cone. In order to get an exhaustive solution without losing possible locations due to approximation errors, we consider that an object that intersects the boundary of a directional cone is in that directional cone. In such a case, t_A (resp. t_B) is tangent to object A (resp. B).

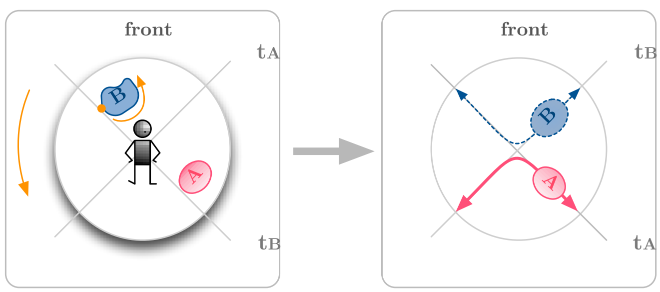

Fig. 4. Orientation constraint principle

Let us consider two surface objects A and B (Fig.5), and P_B (resp. P_A) the tangent point to B and tangent line t_B (resp. t_A). In order to identify the observer location for which object B is in front of him, and object A behind, space is discretized by uniformly moving point P_B (resp. P_A) along the boundary of object B (resp. A). For each location of point P_B (resp. P_A),

1. Construction of tangent t_B (resp. t_A).
2. Construction of the exterior tangent t_A to object A (resp. t_B to object B) that is also perpendicular to t_B (resp. t_A) [1].

[1] The interior tangent is not necessary since the resulting points are included in the solution.

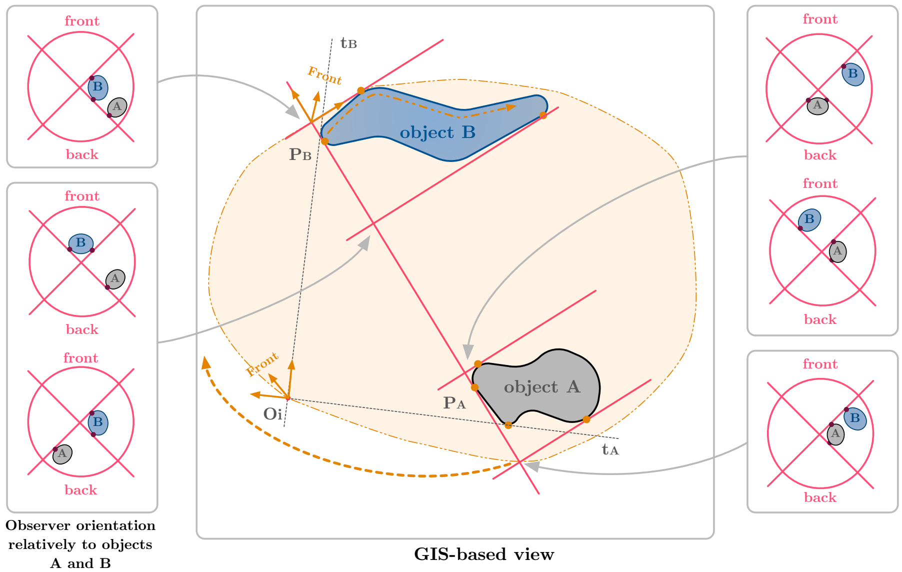

Fig. 5. Orientation constraint

The intersection O_i of t_A with t_B gives a boundary point of the solution, *i.e.*, a boundary point for the possible location of the observer. Consequently, the region $\mathcal{A}(object_A, object_B)$ in which the observer should be located is bounded by the convex hull materialized by points $O_1, \ldots, O_m$ with m $\in \mathbb{N} \setminus \{0\}$. The algorithm is similar when objects A and/or B are modeled as polylines or points. The difference with polylines is given by the intersection between t_B and B (resp. t_A and A) that can then be a segment rather than a point.

Figure 5 illustrates the possible observer locations with respect to two objects A and B, when considering their relative locations to the observer. The solutions presented to the left and right of the figure show the range of the observer positions that fulfill the direction constraints. This algorithm is applied to all object pairs of the geographical database whose classes correspond to those of the entities located in two opposite directional cones. Let us consider the following example " the castle is in front of me, and the valley behind ", the previous algorithm is then applied to all object pairs ("castle", "valley") of the geographical database that also belong to the previous solution S_{vis}. Let $\mathbb{E}_{C1}$ be the set of entities of the verbal description that are in a directional cone (*e.g.* $\mathbb{E}_{front}$), and $\mathbb{E}_{C2}$ the set of entities of the verbal description that are in the opposite cone (*e.g.* $\mathbb{E}_{back}$), $\mathbb{E}_{C1/2}$ the set of combinations of entity pairs (e_i, e_j) of the verbal description with $e_i \in C1$ and $e_j \in C2$, $\mathbb{O}_{C1}$, $\mathbb{O}_{C2}$, $\mathbb{O}_{C1/2}$ the corresponding set of objects and combinations of objects (o_m, o_n) of the GIS, and $\mathcal{A}(o_m, o_n)$ the solution region with $o_m \in \mathbb{O}_{C1}$ and $o_n \in \mathbb{O}_{C2}$. The solution region $S_{opposite\_rel}$ for which some objects are in a cone (*e.g.* front) and others in the opposite one (*e.g.* back) is the union of regions $\mathcal{A}(o_m, o_n)$. When space is partitioned with four directional cones, a possible solution $\mathbf{S}_{dir}$ is given by the intersection of the two sub-solutions regions that correspond to the solutions front/back and right/left.

Let N_B and M_B denote the intersections of the interior tangents t_A and t_B with object B. When space is partitioned by two subspaces, *i.e.*, front/back or right/left, the solution is given by uniformly moving point P_B along the boundary of object B from points N_B to M_B (Fig.6). For each P_B, a solution $\mathcal{S}^i_{P_B}$ given by the half space behind object B fulfills the constraint for which B is in front of the observer (*i.e.*, the observer is behind B). A similar method is applied to object A. For each P_A, a solution $\mathcal{S}^i_{P_A}$ given by the half space is front of object A. $\mathbf{S}_{dir}$ corresponds to the intersection of the two sub-constraints, *i.e.*, $\mathbf{S}_{dir} = \cap(\mathcal{S}^i_{P_B}, \mathcal{S}^i_{P_B})$.

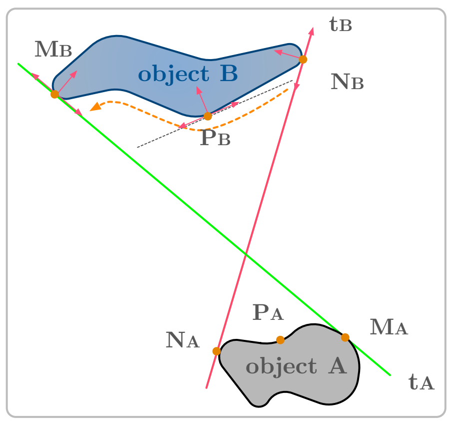

Fig. 6. Orientation constraint (two cones)

Case 2. Entities in an identical cone Let us consider a second case where two entities are located in a same directional cone, *i.e.*, entities related to the observer in a similar way. An equivalent algorithm is applied with the difference that it identifies the possible locations of the observer by computing the limits for which objects A and B are in a same cone. The solution region $\mathbf{S}_{dir\_cone}$ is the complement of solution given by Case 1.

When space is partitioned by two directional cones (front/back or right/left), the solution is constructed by uniformly moving point P_B (resp. P_A) along the boundary of object B (resp. A) from points N_B to M_B (resp. N_A to M_A) that constitutes the intersection of the exterior tangents t_A and t_B to object B (resp. A). The solution is given by the exterior region bounded by the convex hull between A and B.

Case 3. Distance relations Distance relations, whether used in an egocentric or allocentric manner, are also integrated in the geopositioning process. Their

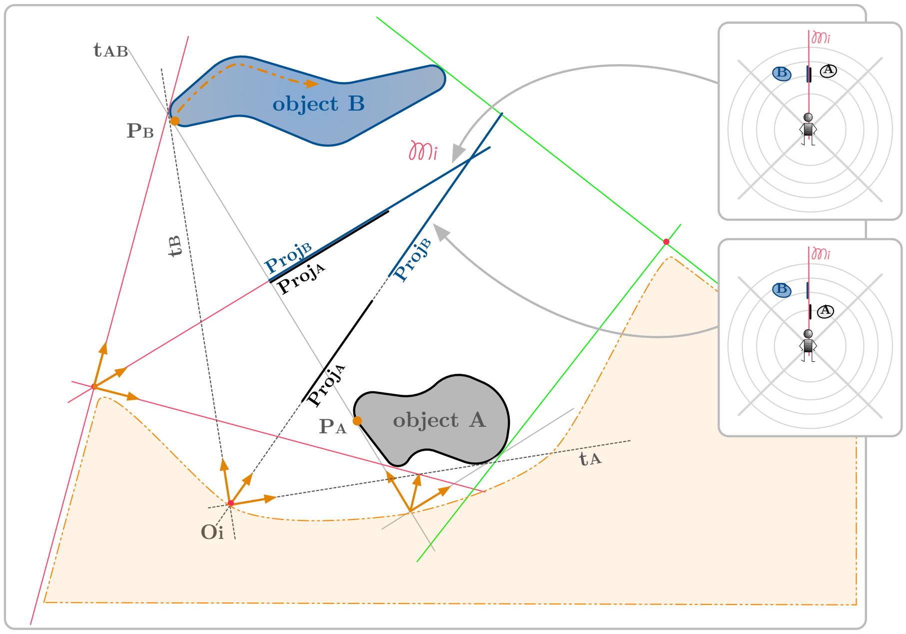

Fig. 7. Distance constraint

interpretation is given by the use of the proximity spaces that structure the conceptual map. When some entities are located in an identical directional cone, they can be located in different or similar proximity spaces with respect to the location of the observer. Figure 7 illustrates an example of distance constraint satisfaction where object A is in front of the observer, and B is behind A. The space $\mathcal{S}_{distance}$ that satisfies the two constraints also refers to the possible locations of the observer. The principle consists in finding the limits of the observer's location with respect to the following constraints:

– Entities A and B are in an identical directional cone.
– Their distances relatively to the observer correspond to those supported by the conceptual map.

When searching for a candidate location of the observer relatively to objects A and B as illustrated in the previous example, the search method is as follows. Space is uniformly discretized by uniformly moving point P_B (resp. P_A) along the boundary of object B (resp. A). For each location of point P_B (resp. P_A), tangents t_B and t_A are constructed. The relative ordering of the different entities composing the environmental scene is defined by projecting entities A and B on the median line that bisects angle $\widehat{t_A, t_B}$ (Fig. 7). The interval endpoints are compared one to the other, as applied elsewhere in unidimensional spaces [26].

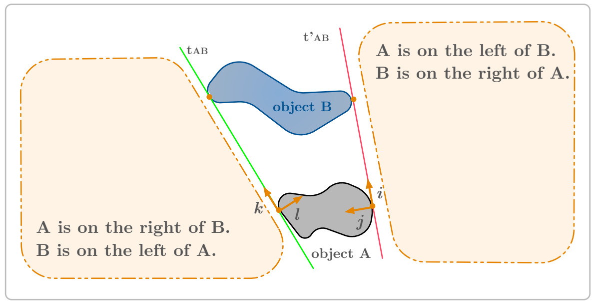

Fig. 8. Relative direction constraint

We consider that B is behind A when their endpoint beginnings (relatively to the observer) coincide. This search algorithm is similarly applied when the observed entities are represented as polylines. The difference is given by the fact that the intersection between t_B and B (resp. t_A and A) can be a segment line rather than just a point. However, it is worth noting that a partition of space based on two directional cones does not enable the identification of a candidate solution.

Case 4. Ternary direction relations Let us consider the case of a ternary relation using an observer-centered frame of reference [27], *i.e.*, *"on the left of"* or *"on the right of"* between two distinct entities of an identical directional cone. If the observer identifies object A as being on the left of B, it means that he/she is in a half-space defined relatively to the location of A and B. Let t_{AB} and t'_{AB} the exterior tangents of objects A and B, and $(M, \overrightarrow{i}, \overrightarrow{j})$ and $(N, \overrightarrow{k}, \overrightarrow{l})$ the basis as illustrated by Figure 8. On the one hand, if "A is on the left of B", a solution is provided by the half-space such as $S_{ternary} = \{\overrightarrow{j} < 0\}$ .On the other hand, if "A is on the right of B", a solution is provided by the half-space such as $S_{ternary} = \{\overrightarrow{l} < 0\}$. The algorithm is similar when entities A and/or B are modeled as polylines or points.

Integration of the successive results The successive constraints can be summarized as follows:

- $\mathcal{S}_{dir}$ is the space for which opposite direction constraints given relatively to the observer between two entities are satisfied.
- $\mathcal{S}_{dir\_cone}$ is the space for which location constraints between two entities of a similar directional cone are satisfied.
- $\mathcal{S}_{distance}$ is the space for which distance constraints between two entities of a same cone are satisfied.
- $\mathcal{S}_{ternary}$ is the space for which direction constraints given relatively to two entities are satisfied.

Overall, the final solution, *i.e.* the areas that correspond to the possible observer's locations are given by the intersection of the solutions provided by each of these constraints. Since the geopositioning algorithm successively applies these complementary constraints, it significantly reduces the size of the solution space. Let us consider the spatial configuration given by the verbal description " I am in front of a meadow and the castle is behind me. The drawbridge is behind the castle " and illustrated by the conceptual map of figure 3. The application of the parser leads to the identification of three triplets, *e.g.*, [meadow, in-front-of, observer], [castle, behind, observer] and [drawbridge, behind, castle]. The visibility algorithm identifies a first solution region $\mathbf{S}_{vis}$ and the corresponding object candidates. Four spatial constraints emerge from the previous example and are applied to each candidate object:

– the first case where *entities are in opposite directional cones* is applied both on pairs ("meadow", "castle") and ("meadow", "drawbridge").
– the second case where *entities are in an identical cone* is applied on the pair ("castle", "drawbridge").
– the third case that characterizes a distance relations between entities of a same cone is applied on the pair ("castle", "drawbridge").

Consequently, four possibles solution spaces $\mathcal{S}_{dir\_}1$, $\mathcal{S}_{dir\_}2$, $\mathcal{S}_{dir\_cone}$ and $\mathcal{S}_{distance}$ emerge. The final solution is given by their intersection including the previous solution $\mathcal{S}_{vis}$ (Fig. 9).

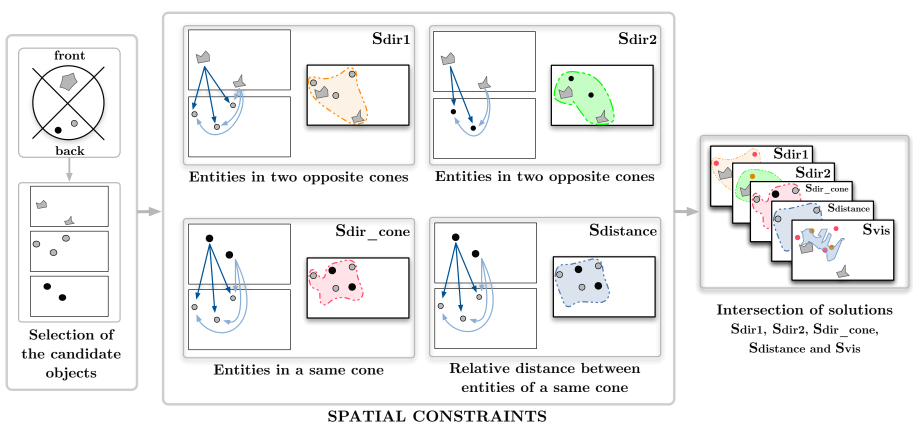

Fig. 9. Constraint-based approach

4 Conclusion

Early models of geopositioning processes have been widely influenced by quantitative representations of space. However, these approaches do not completely reflect the way humans perceive and describe their environment since they preferably process qualitative information. This paper introduces a method for geopositioning an observer from the verbal description of his/her surroundings. A constraint-satisfaction algorithm is applied by successively refining the candidate locations of the observer. The first case of the approach considers some visibility constraints on the entities identified in the verbal description with respect to some candidate objects of the geographical database. The second case considers direction and distance relations as spatial constraints, *i.e.* relative directions between entities and the observer, as well as distance relations are interpreted. Overall the geopositioning approach provides a set of possible locations for the observer. The algorithm still deserves integration of additional spatial relations, such as non-visibility constraints that can be derived from entities and landmarks not identified by the observer, but present in the geographical database. The approach is currently being implemented as an extension of the *GvSIG* software.

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