A wayfinding Application Based on the Influence Area Spatial Model

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Abstract

In this paper we present a qualitative model of space based on the notion of influence area which is a portion of space surrounding an object. We discuss the cognitive foundation of the concept of influence area and show how it can be used to formally define the notions of neighborhood, distance and orientation. We show how this model allows us to convert an analogic representation of spatial objects (in a spatial conceptual map) into an equivalent logical representation in order to carry out various kinds of spatial reasoning. Then, we present a wayfinding application that uses this logical representation and produces a route and its description in natural language. Finally, we briefly discuss the cognitive plausibility of the results provided by the system that implements our model.

1. Introduction

In the GRAAD[1] project we aim at developing a knowledge-based system that manipulates spatial and temporal knowledge while simulating the kind of behavior that people adopt when describing a route. We developed the GRAAD system which is able to generate route descriptions that are similar to those created by human subjects in similar experimental circumstances. In this paper we briefly present the topological model on which GRAAD is based and we discuss the main characteristics of the wayfinding sub-system.

When it comes to the definition of topology, most existing qualitative models lack a definition of the neighborhood relation. They generally address all or a part of the eight basic topological relations defined by Hernandez [Hernandez 1994] and by Randell, Cohen and Cui [Randell et al. 1992]. These relations do not include neighborhood because the topological approach used by these spatial models is only based on connectivity relations. Therefore, when there is no connectivity between objects in a scene, these models are inadequate. As an alternative to solve this problem, and since qualitative spatial reasoning is one of the main characteristics of human behavior, we think that understanding human perception of space and considering the cognitive mechanisms involved in human spatial reasoning provide useful insights to adequately define topological relations. In this paper, we use a new definition of topology based on the concept of influence area that allows a qualitative representation and exploitation of the interaction of spatial objects and the surrounding space. In Section 2, we present the characteristics the conceptual data structure on which our qualitative model is based. In Section 3, we discuss the cognitive foundation of the concept of influence area and then we present the formal definition of topology, neighborhood, distance and orientation. In Section 4 we describe how the model allows us to convert an analogic representation of spatial objects into an equivalent logical representation in order to carry out various kinds of spatial reasoning. In Section 5, we present a wayfinding application that uses this logical representation and produces a route and its description in natural language. In the conclusion, we discuss the cognitive plausibility of the results provided by the system that we developed.

[1] GRAAD is a shuffle of the first letters of the following title: Artificial Agent for Generation and Description of Routes.

2. From mental images to conceptual maps

Since spatial qualitative reasoning is a characteristic of human behavior, it seems appropriate to start with a cognitive study of human generation of route determination and description [Golledge 1992]. We started from a study of pedestrian route descriptions in urban environments generated by human subjects [Gryl 1995]. The analysis of these corpora led Gryl to the determination of two structural components: local descriptions and paths.

A local description corresponds to a place of the environment where the addressee will have to change its orientation, or a place which is worth presenting because it is noteworthy or difficult to recognize. Paths correspond to parts of the displacement through which the addressee is supposed to move while advancing in the same direction.

Paths connect local descriptions. Usually, local descriptions contain references to landmark objects and to their relative spatial positions with respect to other objects or to the addressee.

The relative positions of objects are expressed using various kinds of spatial relations such as neighborhood relations, topological relations and orientation relations. In these natural language descriptions two main elements are found [Gryl 1995]: verbal expressions and nominal expressions.

Verbal expressions are verbal propositions used to express onward moves (such as “to walk straight ahead”; “to walk as far as x”, where x is an object of the environment), orientation changes (such as “to turn right”) or localizations (such as “to be in front of y”, where y is an object of the environment). Nominal expressions are common or proper names or nominal propositions that are used to refer to objects of the urban environment.

As human spatial reasoning is based on the analogical perception of space [Lynch 1960], [Tversky 1993], [Timpf et al. 1992], we use in our model a data structure that preserves the analogical and topological properties of space and respects the experimental results of [Gryl 1995]. We call this data structure a Spatial Conceptual Map (SCM). A SCM is an abstraction of a real map representing a portion of the urban environment and is composed of landmark objects and medium objects.

Medium objects (we also call them Ways) define areas on which the people can move, such as streets, roads and highways or simply trajectories and virtual connections between objects. Landmark objects such as buildings and monuments are used to help people to identify noticeable elements of the urban environment along the medium objects defining the route [Moulin, Gryl and Kettani 1997]. In our model, a SCM is used in a similar way as a mental image is used by a human user in order to carry out qualitative spatial reasoning. Landmark objects and medium objects are positioned in the SCM in a way that respects the layout of the corresponding geographical map: the relative positions of objects are preserved but distances may not be completely accurate. This is cognitively sound since human beings are better at reasoning qualitatively on spatial information. We deal with the wayfinding problem by simulating the displacements of a virtual pedestrian along the Ways of the SCM.

3. Using the influence area concept to define the new model

Several researchers, such as [Denis 1989], [Biederman 1987] and [Gahegan 1995], think that human beings mentally build an influence area (IA) around spatial objects that they perceive in their environment. According to these researchers, the IA allows people to contextually reason, to evaluate metric measures, to qualify positions and distances between objects, etc.. That is to say that influence areas allow people to qualitatively reason about space.

As an illustration on how people use the IA in their spatial reasoning, suppose that we want to compare the distance between two Himalayan's mountains. Suppose also that this distance is about 5km. We would surely say that these two mountains are close, given that they are very big comparing to the distance that separates them. Now, suppose that we want to compare two cars separated by the same quantitative distance (5km), we would say that those cars are far given that they are relatively small comparing to the distance that separates them. We can see that instead of dealing with the same quantitative distance, our reasoning can be influenced by the relative importance of objects and their associated influence areas.

In our approach, we define the notions of neighborhood, distance and orientation using the concept of influence area [Moulin, Kettani 1997] as we show in the next sub-sections.

3.1. Qualitative definition of

Neighborhood

Let us now define formally the concept of influence area. Given an object O of any shape, an influence area IA of O is a portion of space surrounding O such that (Figure 1): IA has two borders (an interior border and an exterior border); IA's borders have the same shape as O's border; if from any point Oi located on O's border BO we draw a perpendicular line, this line crosses IA's interior border at point IAIBi and IA's exterior border at point IAEBi such that ($\forall$ Oi $\in$ BO) (dist(Oi,IAIBi) = c1 and dist(Oi,IAEBi) = c2 and c1>c2). The distance dist(IAIBi,IAEBi) is called the width of the influence area.

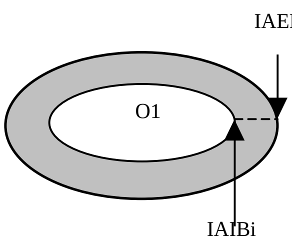


Figure 1: Illustration of IA of objects

Now, the qualitative definition of neighborhood can be formulated as follows:

Object O_2 is a neighbor of object O_1 IFF ($O_2 \cap IA(O_1)) \neq \phi$

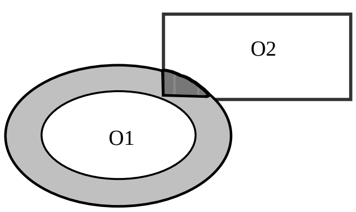


Figure 2: Neighborhood and influence area

3.2. Qualitative definition of Distance

This notion of neighborhood can only be used to specify that two objects are close or not. It cannot yet handle the subtle way that people qualify distances between objects. Hence, we propose to construct multiple influence areas around each object, where each IA would represent a certain degree of proximity, that is to say, a certain qualitative distance to the objects. For example, we can define 3 influence areas (Figure 3) that simulate the qualitative distances expressed in natural language such as: very close (vc), close (c) and relatively far (rf). Hence, the qualitative definition of distance is now formulated as follows:

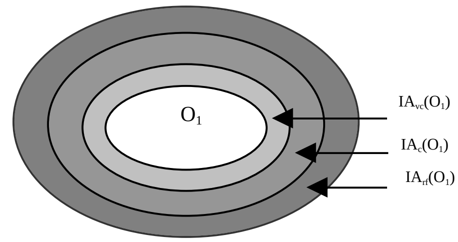


Figure 3: Distance and influence area

Object O_2 is at a certain degree of proximity (dp) of Object O_1 IFF ($O_2 \cap IA_{dp}(O_1)) \neq \phi$ where $IA_{dp}(O_1)$ denotes the influence area characterizing the qualitative distance dp to Object O_1.

3.3. Qualitative definition of Orientation

In our model, we adopt Hernandez' approach to orientation [Hernandez 1994]. We decompose the plan surrounding any spatial object O_1 into a fixed number of orientation areas denoted $O_{1,\ OZ}$ with respect to the intrinsic orientation of the object. For example, the front left of an object O would be denoted: $O_{Front\text{-}eft}$. Furthermore, we think that orientation and neighborhood relations are related and should be integrated in a unified definition. Hence, we propose the following definition that takes into account both orientation and neighborhood relations:

O_2 is at a certain degree of proximity (dp) of O_1 viewed from its orientation area OA IFF ($O_2 \cap IA_{dp}(O_{1,\ OZ})) \neq \phi$ where $IA_{dp}(O_{1,\ OZ})$ denotes the intersection of the portion of influence area $IA_{dp}(O_1)$ with the orientation area $O_{1, OZ}$

4. Exploiting the analogical representation

This section describes how to handle the analogical representation that we use in our model in order to obtain an equivalent logical representation on which we can carry out the qualitative spatial reasoning.

In a route description typical instructions involving landmark objects specify a neighborhood or an orientation relation between the current position and the landmark object which can be expressed in terms of topological relations thanks to the introduction of influence areas. In addition to the relative spatial positions of landmark and medium objects, a SCM contains the influence areas of these different objects as well as specific information such as allowed traffic directions on Ways and front orientations for landmark objects.

Since a route from point A to point B is a path composed of a succession of Way segments, it is natural to try to characterize the portions of Ways to which we can apply the expressions found in human route descriptions. Hence, given a spatial conceptual map S and a Way object Wx, let us consider the set CLO(Wx, S) of landmark objects Oj contained in S whose closeness influence areas have a non empty intersection with Wx [Moulin, Kettani 1998]:

- CLO(Wx, S) is the set of landmark objects Oj contained in S whose closeness influence areas have a non empty intersection with Wx: $(\forall$ Oj $\in$ CLO(Wx, S)) (CTOj $\cap$ Wx $\neq \emptyset)$;
- IWO(Wx, S) is the set of Way objects Wy contained in S which have a non empty intersection with Wx, (denoted INT(Wx, Wy)): $(\forall$ Wy $\in$ IWO(Wx , S)) (Wy $\cap$ Wx = INT(Wx , Wy) $\neq \emptyset)$.

Given CLO(Wx, S) and IWO(Wx, S), and using our model definitions' of neighborhood, distance and orientation, it is possible to partition the portion of Wx contained in S into a set of n_x consecutive segments $W_{x[k]}$ for k = 1, n_x such that one of the 4 following cases holds:

(c1). $W_{x[k]}$ is marked by at least one landmark object: ($\exists$ Oj $\in$ CLO(Wx, S)) (CTOj $\cap$ Wx = $W_{x[k]}$);

(c2). $W_{x[k]}$ is a crossing of Ways: ($\exists$ Wy $\in$ IWO(Wx, S)) (Wy $\cap$ Wx = $W_{x[k]}$) ;

(c3). $W_{x[k]}$ is an intersection between a crossing of Way with Wx and closeness influence areas of one or several landmark objects;

(c4). $W_{x[k]}$ is a straight unremarkable Way segment such that: $(\forall$ Oj $\in$ CLO(Wx, S)) (CTOj $\cap$ $W_{x[k]} = \emptyset$) AND $(\forall$ Wy $\in$ IWO(Wx, S)) (Wy $\cap$ $W_{x[k]} = \emptyset$).

We call a *Way Elementary Area* (WEA) any segment $W_{x[k]}$ that is part of a Way Wx in the SCM. Given a point A of a SCM S located in a WEA $W_{u1[m]}$ and a point B located in a WEA $W_{u2[n]}$, a route $R_{A,B}$ from point A to point B is a succession of adjacent WEAs that connect A to B. The corresponding set of portions of Ways is denoted RWP($R_{A,B}$,S).

Hence a route $R_{A,B}$ is a succession of route segments $R_{A,B[k]}$ for k =1 to p such that:

- $R_{A,B[1]}$ = Wu1[m];
- $R_{A,B[p]}$ = Wu2[n];
- For any k such that 1 < k < p, $R_{A,B[k]}$ is a portion of Way or a crossable object such that:

  $(\exists$ ux) $(\exists$ q) (Wux[q] $\in$ RWP($R_{A,B}$, S) AND $R_{A,B[k]}$ = Wux[q]).

Hence, each segment of the route can be identified and logically defined using cases c1 to c4, thanks to our model definitions' of neighborhood, distance and orientation. That means that the model we propose provides a mechanism to transform an SCM, which is an analogical representation of space, into a set of logical partitions in order to apply a qualitative spatial reasoning on it. These partitions can be used in a variety of spatial reasoning such as wayfinding, itinerary descriptions [Moulin, Kettani 1998], spatial analysis, risk assessment, etc..

We discuss in the next section how to apply our model to a wayfinding problem.

5. A wayfinding application

To illustrate how to manipulate the logical partitions of our model and use them in qualitative spatial reasoning, we developed a software agent that uses these partitions in order to find a way between two given locations in a SCM. In our approach, a valid path between two points A and B is composed of a succession of adjacent segments that start at A's localization and end at B's localization.

One of the main properties of the WEAs is their connectivity. In fact, this relation allows us to know, at any time and from any WEA, what are the possible displacements of the virtual pedestrian. Figure 4 presents a portion of a SCM containing 7 landmarks denoted O_i, 4 Ways denoted W_i and a set of WEA denoted α_i. The partitioning of the Ways enables us to define all the possible displacements from any WEA thanks to the connectivity relation.

In wayfinding applications, people usually use a specific criteria in order to choose the «best candidate» among all possible candidates for the next displacement. Empirical evidence shows that one way human subjects establish an itinerary to reach a target object is based on the minimization of the angle between a fixed orientation (the north for instance) and the estimated orientation of the target object relative to the human subject. We call that angle «the human subject's vision to the target object».

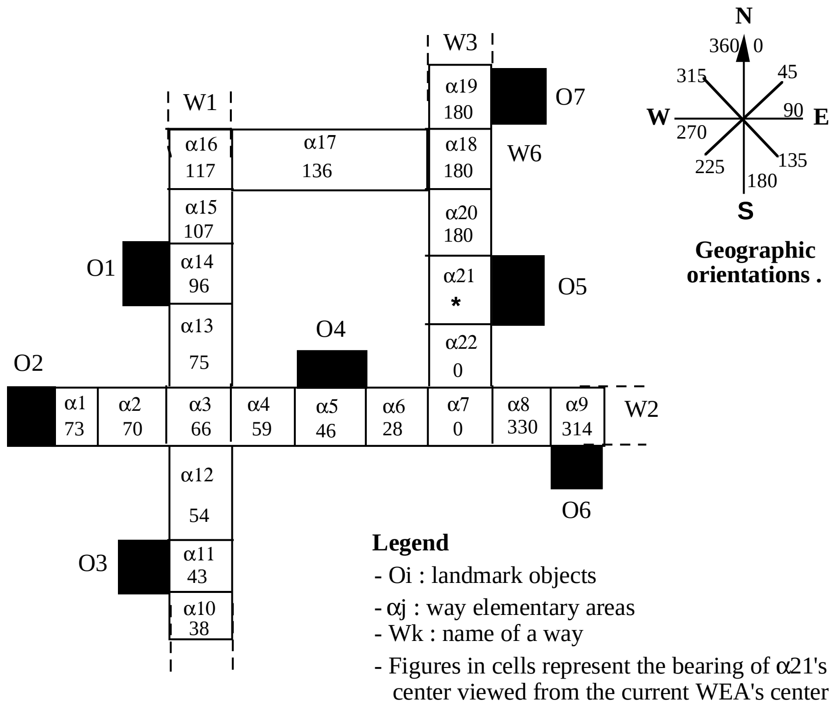


Figure 4: Example of a partitioned SCM

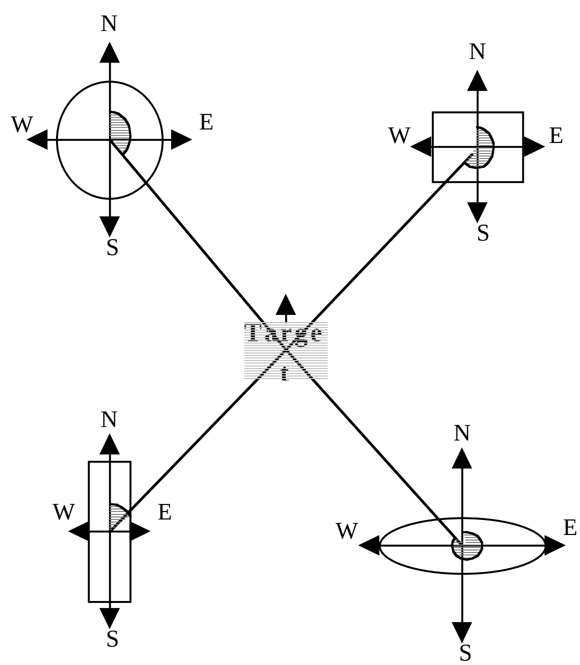
The approach that uses the minimization of the vision angle criteria perfectly agrees with our model. It consists in systematically minimizing the vision angle to the target between the current position and its next displacement with respect to a target position. All possible candidates for next the displacement are evaluated with respect to the minimization of vision angle criteria and the best one is chosen. To this end, we should systematically:

(1)- evaluate the angle between the current position αi and the target position αt (denoted $\theta_T(\alpha i, \alpha t)$);

(2)- consider the orientation of displacement between the current position αi and the next candidate position αj for a displacement (denoted $\theta_d(\alpha i, \alpha j)$) and;

(3)- correlate (1) and (2) to deduce the vision angle to the target for of the candidate displacement.

In Figure 5, we put a target object in the center of a SCM and 4 landmark objects, each being localized in a particular cardinal direction. We indicate the angle that corresponds to θ_T using grey color. In Figure 4, we indicate the value in degrees of θ_T between each WEA of the SCM and the target WEA α21.



For example, to identify the best displacement candidate to reach α21 from α11, we must compare the candidate displacement (α11 to α10) and the candidate displacement (α11 to α12). Both candidate displacements have the same θ_T (α11, α21, which is equal to 43. The angle θ_d (α11, α12) corresponds to the north direction (which is equal to 0) while θ_d (α11,α10) corresponds to the south direction (which is equal to 180). The vision angle measure corresponds to the absolute value of θ_d-θ_t. Hence, the displacement candidate (α11 to α10) is better than the displacement candidate (α11 to α12) because it corresponds to the minimum vision angle between (/0-43/=43) and (/180-43/=137).

In order to reason about WEAs and displacements we use a Matrix of Orientation and Adjacency (MOA) which contains relevant information about angle evaluation and displacement direction that are used by the path determination algorithm. The columns and lines of the MOA represent the WEAs of the SCM and each cell of the matrix MOA(i,j) (where i and j respectively correspond to the column αi and the line αj) contains information about adjacencies and relative orientations.

We present in Figure 6 an example of a MAO. If a landmark object Ox is close to a WEA αi, we indicate CLT Ox in the cell MOA(i,i). For example, MOA(5,5) indicates that Object O5 is close to WEA α5. When two WEAs αi and αj are adjacent in the SCM, we indicate in the corresponding matrix cells the orientation of possible displacements between these WEAs in the SCM: MOA(αi,αj) contains the orientation (expressed in degrees or using the initials of the cardinal geographic orientations) of the allowed displacement between αi to αj. For example, MOA(α4,α5) contains E which means that α5 is localized in the East of α4. In addition, we indicate in each matrix cell MOA(αi,αj), the orientation of the center of WEA αi relative to the center of WEA αj.

Now using the MOA, the general algorithm to find a way between points A and B each localized in a WEA of the SCM, can be formulated as follows:

FindWay(WEA_A, WEA_B)

Begin

Read A as the location of departure;

Read B as the location of arrival;

Deduce the WEA corresponding to A (WEA_A);

Deduce the WEA corresponding to B (WEA_B);

While WEA_A <> WEA_B Do

Begin

Localize the row's entry of the WEA_A in the MOA;

Scan this row and construct a list of possible displacements candidates from WEA_A;

Classify the candidates' list with respect to the vision angle approach using the MOA;

Select the first candidate of the candidates' list as the new candidate;

Replace WEA_A by the WEA_X of the new candidate;

FindWay(WEA_X, WEA_B);

End;

End.

This algorithm will end when a way is found or when all possible displacements from all candidates would be explored.

The way nodes are incremented at each recursive call by the departure parameter of the FindWay function.

To classify the candidates' list, we use the MOA that contains all the necessary information about orientation and adjacency and we calculate both θ_d and θ_t angles to deduce the measure of the vision angle of each candidate.

Figure 7 presents a table that shows, step by step, how the route between α11 and α21 has been determined. As a general rule, to determine the measure of the vision angle of a given displacement, we must select the minimum value between /θ_D-θ_T/ and /360+θ_D-θ_T/.

The criteria of angle minimization reflects a strategy where a person has a general and global view of its environment. She tries, in fact, to reach its destination without thinking about intermediate steps, considering that there is a certain consistency in the network of Ways that will prevent a sudden discontinuity on the connectivity of ways. But this is not the case in certain urban configurations and the algorithm could provide bad results. In fact, there can be several long detours before reaching the destination. In order to avoid such a situation, we propose an alternative strategy that consists in choosing, among all possible displacements, the one that minimizes the distance between to the current WEA and the target WEA.

Of course, this strategy also has its limits case which arise when the route contains multiple minuscule segments that make it unacceptable.

↙	α1	α2	α3	α4	α5	α6	α7	α8	α9	α10	α11	α12	α13	α14	α15	α16	α17	α18	α19	α20	α21	α22	
α1	CLT **O2**	W																					
α2	E		W																				
α3		E		W								N	S										
α4			E		W																		
α5				E	CLT **O4**	W																	
α6					E		W																
α7						E		W												S			
α8							E		W														
α9								E	CLT **O6**														
α10											S												
α11										N	CLT **O3**	S											
α12			S								N												
α13			N											S									
α14													N	CLT **O1**	S								
α15														N		S							
α16															N		W						
α17																E		W					
α18																	E		S			N	
α19																		N	CLT **O7**				
α20							N														S		
α21	73	70	66	59	46	28	0	330	314	38	43	54	75	96	107	117	136	180	180	N 0	CLT **O5**	S 180	
α22																		S			N		

Figure 6: Matrix of Orientation and Adjacency

Current WEA	**Bearing of target WEA**	**Adjacent WEAs and move orientations**				**Chosen nextWEA**	**Displacement orientation**
α11	43	α10 / 180	α12 / 0			α12	0
α12	54	α11 / 180	α3 / 0			α3	0
α3	66	α12 / 180	α13 / 0	α2 / 270	α4 / 90	α4	90
α4	59	α3 / 270	α5 / 90			α5	90
α5	46	α4 / 270	α6 / 90			α6	90
α6	28	α5 / 270	α7 / 90			α7	90
α7	0	α6 / 270	α8 / 90	α22 / 0		α22	0
α22	0	α7 / 180	α21 / 0			α21 *	0

Figure 7: Illustration of wayfinding algorithm

6. Conclusion

In this paper we described the main characteristics of a qualitative spatial model based on the concept of influence area. We introduced the SCM data structure that we use in our model and showed how it preserves the analogical and topological properties of space. We then discussed the cognitive basis of the notion of influence area and used this notion to formally define neighborhood, distance and orientation. We finally presented an algorithm that uses our qualitative spatial model in order to find a way between two spatial localizations.

We would like to briefly discuss about the cognitive plausibility of the results provided by the GRAAD system. We performed a formal experiment involving 20 human subjects [Kettani 1999]. The main goal of this experiment was to know if routes and the corresponding natural language descriptions generated by GRAAD could be distinguished from the routes and descriptions generated by human subjects in similar experimental situations. To this end, we used GRAAD to generate a route and its natural language description between two specific localizations. We then asked each subject to generate a route and its natural language description between the same localizations. We put together the human and the artificial routes and descriptions and asked each human subject to analyze them and to tell us if she could distinguish specific routes and descriptions for any reason (automation, redundancy, style, structure, etc.). Only one person could distinguish the descriptions generated by GRAAD, while several human descriptions have been qualified as "automatically generated". The result of this experience is positive in that it confirms the cognitive plausibility of our approach.

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