A Spatial Model Based on the Cognitive Concept of Influence Area

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Abstract

In this paper we present a qualitative model of space based on the cognitive concept of influence area which is a portion of space surrounding an object. We discuss the foundation of this concept and show how it can be used to formally define the notions of neighborhood, distance and orientation. We show how this model can be used to solve concrete problems and we present a Route Description application that we have developed and implemented in the GRAAD System. We discuss the cognitive plausibility of the outputs provided by GRAAD which are route description similar to those produced by human subjects. We also describe an experiment that we performed in order to compare GRAAD’s outputs with route descriptions created by human subjects in similar experimental conditions. The results of this experiment confirm the cognitive plausibility of GRAAD’s outputs.

1. Introduction

Most existing qualitative spatial 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. 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. Starting from this idea, we developed a Cognitive Spatial Model that is based on human perception of space and we implemented a software agent called GRAAD1 that manipulates spatial and temporal knowledge while simulating the kind of behavior that people adopt when describing a route. GRAAD is able to generate routes and route descriptions that are similar to those created by human subjects in equivalent experimental circumstances.

In this paper we do not focus on the spatial model itself (see [Kettani & Moulin 1998] and [Moulin & Kettani 1998b]) but on its cognitive plausibility. We briefly present the theoretical basis of our model and describe how it can be used to solve real spatial problems. We then describe an experiment that we performed which involved GRAAD and human subjects. The goal of this experiment was to know if routes and their corresponding natural language descriptions generated by GRAAD could be distinguished from routes and descriptions generated by human subjects. We will finally discuss how the results that we obtained during this experiment confirm the cognitive plausibility of our model.

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1 GRAAD is a shuffle of the first letters of the following title: Artificial Agent for Generation and Description of Routes.
2. Characteristics of the proposed model

Since we aim at elaborating a spatial cognitive model, it seems appropriate to start by studying the literature related to imagery and human spatial reasoning. As several researchers such as [Denis 1989], [Biederman 1987] and [Gahegan 1995], we believe that human beings mentally build an influence area (IA) around spatial objects that they perceive in their environment. The notion of influence area is an abstraction of the way that objects influence people’s vision and perception of scenes. It is proportional to the salience of objects in the environment.

As an illustration on how people use influence areas when reasoning about space, consider the following example. Let us suppose that we want to compare the distance between two Himalayan mountains and that this distance is about 10km. We would surely say that these 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 (10km). We would say that those cars are very 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.

We think that the IA is one of the main elements that allow people to contextually reason about space, to evaluate metric measures, to qualify positions and distances between objects, etc.. Hence, a spatial model that is based on this concept would be able to take into account the neighborhood relation and then solve problems we mentioned in the introduction of this paper. We will now define the formal basis of a qualitative model that is based on the concept of influence area.

2.1. A model based on influence areas

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 (∀ Oi ∈ 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.

It is known that neighborhood, distance and orientation are the main elements that should be defined when elaborating a spatial model [Hernandez 94]. These elements could be defined in an intuitive and spontaneous way thanks to the concept of IA. In fact, the qualitative definition of neighborhood can be formulated as follows:

Object O₂ is a neighbor of object O₁ IFF (O₂ ∩ IA(O₁)) ≠ ∅
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 object (Figure 3).

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:

Object \( O_2 \) is at a certain degree of proximity \( dp \) of Object \( O_1 \) \( \iff \) \( (O_2 \cap IA_{dp}(O_1)) \neq \emptyset \)

where \( IA_{dp}(O_1) \) denotes the influence area characterizing the qualitative distance \( dp \) to Object \( O_1 \).

![Figure 3: Distance and influence area](image)

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: \( O_{\text{Front-Left}} \). 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 \( OA_{I} \) \( \iff \) \( (O_2 \cap IA_{dp}(O_1, O_{1,oz})) \neq \emptyset \)

where \( IA_{dp}(O_1, O_{1,oz}) \) denotes the intersection of the portion of influence area \( IA_{dp}(O_1) \) with the orientation area \( O_{1,oz} \).

2.2. Spatial Conceptual Map

As human spatial reasoning is based on the analogical perception of space [Lynch 1960] [Golledge & Zannaras 1973] [Denis 1989], we use in our model a data structure that preserves the analogical and topological properties of space. It is based on the notion of mental image (mental map). In fact, several researchers have worked on mental maps as a basis for representing configurational knowledge [Golledge 1992]. Several studies [Tversky 1993] [Timpf et al. 1992] showed that most people use some kind of mental model of a region or city part in order to generate and describe a route: they mentally visualize the salient elements characterizing the Way that they want to describe. We call this data structure a Spatial Conceptual Map (SCM).

To identify and characterize the elements that compose a SCM, we use the results of a study of pedestrian route descriptions in urban environments generated by human subjects [Gryl 1995]. This study led 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.

With respect to the results obtained by Gryl, we define a SCM as an abstraction of a real map representing a portion of the urban environment which is composed of representations of landmark objects and medium objects. Medium objects (we also call them Ways) define areas on which 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 person 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.

To illustrate how to use the new spatial model that we propose and to demonstrate its computational feasibility, we developed the GRAAD system that is able to qualitatively reason using a spatial conceptual map [Moulin, Gryl and Kettani 1997], to build routes between different points of the map [Moulin & Kettani 1998a], to simulate the advancement of the Virtual Pedestrian (VP) in the conceptual map [Kettani & Moulin 1999] and to describe such routes using natural language in a cognitively plausible way (agreeing with the way human beings describe routes). In this paper, we will focus on this later issue.

3. An application: route description

As we mentioned in section 2.2, route descriptions generated by human subjects are essentially composed of local descriptions and path descriptions. A route from a point A to a point B is a path composed of a succession of way segments, possibly intersecting with certain crossable places. A specialized module of GRAAD determines a route that can be expressed in terms of local and path descriptions. In this section we show how these descriptions can be generated from the elements contained in a spatial cognitive map.

Since VP moves along the way segments composing a route, it is natural to try to characterize the portions of ways with respect to the expressions found in human route descriptions (expressions of onward moves, orientation changes, description of VP's localization and local descriptions). In fact, most of these descriptions match with specific way portions in a SCM. In this section we propose a formal categorization of way portions in a spatial conceptual map.

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:

\[(\forall Oj \in \text{CLO}(Wx, S)) (\text{CT}_{Oj} \cap Wx \neq \emptyset ).\]

Let us consider the set IWO(Wx, S) of way objects Wy contained in S which have a non empty intersection with Wx, (denoted INT(Wx, Wy)):

\[(\forall Wy \in \text{IWO}(Wx, S)) (Wy \cap Wx = \text{INT}(Wx, Wy) \neq \emptyset ).\]

Let us also consider the set ICO(Wx, S) of crossable objects COy contained in S which have a non empty intersection with Wx, (denoted INT(Wx, COy)):

\[(\forall COy \in \text{ICO}(Wx, S)) (COy \cap Wx = \text{INT}(Wx, COy) \neq \emptyset ).\]
Given the sets $CLO(W_x, S)$, $IWO(W_x, S)$ and $ICO(W_x, S)$, we can partition the portion of $W_x$ contained in $S$ into a set of $n$ consecutive segments $W_{x[k]}$ for $k = 1, n$, such that one of the six following cases holds:

(c1) $W_{x[k]}$ is marked by at least one landmark object: $(\exists O_j \in CLO(W_x, S)) (CT_{O_j} \cap W_x = W_{x[k]});$  
(c2) $W_{x[k]}$ is a crossing of ways: $(\exists W_y \in IWO(W_x, S)) (W_y \cap W_x = W_{x[k]});$  
(c3) $W_{x[k]}$ intersects a crossable object: $(\exists CO_z \in ICO(W_x, S)) (CO_z \cap W_x = W_{x[k]});$  
(c4) $W_{x[k]}$ is an intersection between a crossing of way with $W_x$ and closeness influence areas of one or several landmark objects;  
(c5) $W_{x[k]}$ is an intersection between $W_x$, a crossable object and closeness influence areas of one or several landmark objects;  
(c6) $W_{x[k]}$ is a straight unremarkable way segment such that:  
$$\forall O_j \in CLO(W_x, S) (CT_{O_j} \cap W_{x[k]} = \emptyset) \text{ AND } (\forall W_y \in IWO(W_x, S)) (W_y \cap W_{x[k]} = \emptyset) \text{ AND } (\forall CO_z \in ICO(W_x, S)) (CO_z \cap W_{x[k]} = \emptyset).$$

As an example, let us consider a portion of Paris that was used by Gryl when she carried out her cognitive study (Gryl 1995). Figure 4a presents a portion of Paris’ spatial conceptual map which emphasizes Danton street (Rue Danton) and its intersections with other streets (rue des Poitevins, rue Serpente, rue Mignon, Boulevard St Germain) with a crossable object (Place St André des Arts) and with the closeness influence area of a landmark object (Centre Henri Piéron). Figure 4b displays the nouns of the various portions $W_{Danton[k]}$ that are identified on Danton Street according to our categorization. For instance, INT (Danton, Piéron, Serpente) denotes the intersection of Danton Street with Serpente Street and the closeness influence area of Centre Henri Piéron. The name of unremarkable segments is built using the name of the street and the first letters of the intersecting ways or crossable object. For instance Danton-PS stands for Danton-Poitevins-Serpente.

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1 Here is the interpretation of the set names: CLO stands for CLOseness, ICO stands for Intersection with Crossable Objects and IWO stands for Intersection with Way Objects.
Let us now define a route. In a spatial conceptual map $S$, given a point $A$ located in a crossable object $CO_{u1}$ or in a portion of way $W_{u1}[m]$ and a point $B$ located in a crossable object $CO_{u2}$ or in a portion of way $W_{u2}[n]$, a route $R_{A,B}$ from point $A$ to point $B$ is a succession of adjacent portions of ways and possibly crossable objects that connect $A$ to $B$: the corresponding set of portions of ways is denoted $RWP(R_{A,B},S)$ and the set of crossable objects is denoted $RCO(R_{A,B},S)$. Hence, a route $R_{A,B}$ is a succession of route segments $R_{A,B}[k]$ for $k = 1$ to $p$ such that:

1. $R_{A,B}[1] = CO_{u1}$ OR $W_{u1}[m]$
2. $R_{A,B}[p] = CO_{u2}$ OR $W_{u2}[n]$
3. For any $k$ such that $1 < k < p$, $R_{A,B}[k]$ is a portion of way or a crossable object such that:

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$RWP$ stands for Route Way Portions; $RCO$ stands for Route Crossable Objects.
∃ux, ∃q (Wux[q] ∈ RWP(RA,B,S) AND RA,B[k] = Wux[q]) OR (∃uy) (COuy ∈ RCO(RA,B,S) AND RA,B[k] = COuy)

As we will see in the next section, each route segment can be described in natural language in a similar way as local descriptions and path descriptions are generated by human subjects (Section 2.2). However, let us remark that our approach provides a fine-grained partition of a route.

Local descriptions are specific locations along the route where certain decisions should be taken: decisions to change VP’s current orientation, decisions at locations where an ambiguity may arise and decisions concerned with the identification of specific elements in the environment. Hence, when VP is on a crossable object or on a way segment which conforms to one of the five way segment categories c1 to c5, the GRAAD system has a potential candidate for a local description. Local descriptions are linked by continuation paths which are portions of the route where the same direction is followed by VP. Hence, way segments of category c6 (see Section 4) are good candidates for path descriptions. But, this is also the case for way segments of categories c1, c2 and c4, if VP crosses them without changing its direction. Different path descriptions can be generated depending on which kind of way segment is crossed by VP.

In order to model VP’s movements, we need to specify the temporal and spatial characteristics of its trajectory. In a route description this trajectory is composed of a succession of points which are deemed necessary by the route generator with respect to cognitive constraints (easiness for the generator to explain the characteristics of the route, easiness for the addressee to understand those characteristics).

Hence, a route RA,B is associated with a sequence of relevant instants {t1, t2, ..., tc-1, tc, tc+1, ..., tna} at which a local description or a path description is provided. Obviously, the time intervals [ti, tj] need not be equal. VP’s position in the spatial conceptual map is time dependent and is denoted Pos(VP, tc), where tc is a time stamp identifying the time at which the position has been plotted on the trajectory. The virtual pedestrian is also associated with an intrinsic reference frame providing its front orientation which is denoted Orient(VP, tc), where tc is a time stamp identifying the time at which the corresponding position and orientation have been plotted on the trajectory.

Given a sequence of relevant instants {t1, ..., tna} used to describe relevant portions of a route RA,B which is composed of a succession of route segments RA,B[k] for k =1 to p such that RA,B[k] = Wux[z] or RA,B[k] = COux, where Wux[z] is a portion of way pertaining to RWP(RA,B,S) and COux is a crossable object pertaining to RCO(RA,B,S), we can specify VP’s movements using verbal expressions. Table 1 presents the equations of VP’s position and orientation for some of these expressions. We use the following conventions:

- ORIENT(Wix[k]) represents the orientation of route portion Wix in the direction k of way Wi. A route can be intrinsically associated with two opposite directions: we assume that the succession Wix[k], Wix[k-1], ..., Wix[k+n] defines the direction denoted Orient(Wix[k+n+1]) and that the succession Wix[k], Wix[k-1], ..., Wix[k+n] defines the direction denoted Orient(Wix[k+n-1]);
- CTix denotes the closeness influence area of object Ox. CTix,z denotes a sub-area of the closeness influence area of object Ox which characterizes orientation z in the intrinsic reference frame associated with object Ox;
- INCO denotes the interior area of a crossable object CO.

Table 1 only gives a sample of the various verbal expressions that can be used to specify VP’s movements. Let us comment upon them briefly:

- Case 1 is an example of an onward move: in the previous position (at tc) VP is on way segment Wix with the orientation Orient(Wix[k]) and in the current position (at tc+1) VP is on a subsequent segment of Wix in the same direction k; if n = 0, VP is on the same Wix; if n > 0, VP is on a segment Wix+n in direction k = +1; if n < 0, VP is on a segment Wix-n in direction k = -1.
• Case 2 corresponds to an onward move with the goal of reaching a landmark object Oc: there exists a future position (at $t_{c+n}$) where VP will be at the intersection of a way portion $W_{j[y]}$ and $CT_{Oc}$, the closeness influence area of Oc.

• In case 3 VP crosses the intersection between way $W_i$ and way $W_j$ without changing its orientation: $\text{Orient}(VP, t_j) = \text{Orient}(W_{i[x]}, k)$, crossing the intersection is indicated VP’s position changes from $W_{i[x-e]}$ to $W_{i[x]}$ and $W_{i[x+e]}$, with $e = +1$ or $e = -1$.

• In case 4 we have an orientation change where VP is at the intersection of ways $W_i$ and $W_j$ and changes its orientation in order to follow $W_j$ on its portion denoted $W_{j[y+e]}$, with $e = +1$ or $e = -1$.

• In case 5 we have an individual localization where VP’s current position (at $t_c$) is in the closeness influence area of landmark object Oc, with the same orientation it had previously (at $t_{c-1}$).

• In case 6 VP’s current position (at $t_c$) is in the « front » sub-area of the closeness influence area of landmark object Oc with the same orientation it had previously (at $t_{c-1}$).

• In case 7 VP is in the interior area of a crossable object CO.

<table>
<thead>
<tr>
<th>Verbal expression</th>
<th>VP’s positions</th>
<th>VP’s orientations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1 to keep going</td>
<td>previous: $\text{Pos}(VP, t_{c-1}) \in W_{i(x)}$&lt;br&gt;current: $\text{Pos}(VP, t_j) \in W_{i(x)}$&lt;br&gt;$n$ is a positive or negative or null integer</td>
<td>previous: $\text{Orient}(VP, t_{c-1}) = \text{ORIENT}(W_{i(x)}, k)$&lt;br&gt;current: $\text{Orient}(VP, t_j) = \text{ORIENT}(W_{i(x)}, k)$&lt;br&gt;$n$ is a positive or negative or null integer</td>
</tr>
</tbody>
</table>
| Case 2 to go to Oc | current: $\text{Pos}(VP, t_j) \in W_{i(x)}$
Future: $(\exists n \in \mathbb{Z}) (\exists \emptyset) CT_{Oc} \cap W_{j(y)} \neq \emptyset\ AND \ Pos(\text{VP}, t_{c+n}) \in (CT_{Oc} \cap W_{j(y)})$ | current: $\text{Orient}(VP, t_j) = \text{ORIENT}(W_{i(x)}, k)$<br>future: $\text{Orient}(VP, t_{c+n}) = \text{ORIENT}(W_{i(x)}, k)$ |
| Case 3 to cross way $W_j$ | previous: $\text{Pos}(VP, t_{c-1}) \in W_{i(x)}$
with $e = +1$ OR $e = -1$
current: $\text{Pos}(VP, t_j) \in W_{i(x)} \cap W_{j(y)}$
next: $\text{Pos}(VP, t_{c+n}) \in W_{i(x+e)}$ | previous: $\text{Orient}(VP, t_{c-1}) = \text{ORIENT}(W_{i(x)}), k$
with $e = +1$ OR $e = -1$
current: $\text{Orient}(VP, t_j) = \text{ORIENT}(W_{i(x)}, k)$
next: $\text{Orient}(VP, t_{c+n}) = \text{ORIENT}(W_{i(x+e)}, k)$ |
| Case 4 to turn on way $W_j$ | current: VP is at intersection of ways $i$ and $j$
$\text{Pos}(VP, t_j) \in W_{i(x)} \cap W_{j(y)}$
next: $\text{Pos}(VP, t_{c+1}) \in W_{i(x+e)}$
with $e = +1$ OR $e = -1$ | current: $\text{Orient}(VP, t_j) = \text{ORIENT}(W_{i(x)}, k)$
next: $\text{Orient}(VP, t_{c+1}) = \text{ORIENT}(W_{i(x+e)}, k)$
with $e = +1$ OR $e = -1$ |
| Case 5 to reach Oc | current: $\text{Pos}(VP, t_j) \in CT_{Oc}$ | current: $\text{Orient}(VP, t_j) = \text{Orient}(VP, t_{c-1})$ |
| Case 6 to be in front of Oc | current: $\text{Pos}(VP, t_j) \in CT_{Oc,\text{front}}$ | current: $\text{Orient}(VP, t_j)$ unspecified |
| Case 7 to be on CO | current: $\text{Pos}(VP, t_j) \in IN_{CO}$ | current: $\text{Orient}(VP, t_j)$ unspecified |

Table 1: equations of VP’s position and orientation for some frequently used expressions

As an illustration, let us consider in Figure 5 the virtual pedestrian’s trajectory in which several positions have been identified by the time stamps $t_i$. Here are the position and orientation formulae for each of these points and the corresponding verbal expressions in natural language.

| At $t_0$ | $\text{Pos}(VP, t_0) \in \text{IN}_{\text{Place-St-André}}$ | $\text{Orient}(VP, t_0)$ | You are on St |
André Square
At \( t_1 \): \( \text{Pos}(\text{VP}, t_1) \in W_{\text{Danton \[AP\]}} \)
\( \text{Orient}(\text{VP}, t_1) = \text{ORIENT}(W_{\text{Danton \[AP\]}}, 1) \)
Follow Danton St.

At \( t_2 \): \( \text{Pos}(\text{VP}, t_2) \in W_{\text{Danton \[PO\]}} \cap W_{\text{Poitevins \[DA\]}} \)
\( \text{Orient}(\text{VP}, t_2) = \text{ORIENT}(W_{\text{Danton \[PO\]}}, 1) \)
Cross Poitevins St.

At \( t_3 \): \( \text{Pos}(\text{VP}, t_3) \in W_{\text{Danton \[SE\]}} \cap W_{\text{Serpente \[DA\]}} \)
\( \text{Orient}(\text{VP}, t_3) = \text{ORIENT}(W_{\text{Danton \[SE\]}}, 1) \)
Cross Serpente St.

At \( t_4 \): \( \text{Pos}(\text{VP}, t_4) \in C_T_{\text{Centre Henri Piéron}} \)
\( \text{Orient}(\text{VP}, t_4) = \text{ORIENT}(W_{\text{Danton \[SE\]}}, 1) \)
You are in front of Centre Henri Piéron

At \( t_5 \): \( \text{Pos}(\text{VP}, t_5) \in W_{\text{Danton \[MI\]}} \cap W_{\text{Mignon \[DA\]}} \)
\( \text{Orient}(\text{VP}, t_5) = \text{ORIENT}(W_{\text{Mignon \[DA\]}}, 1) \)
Turn on Mignon St.

At \( t_6 \): \( \text{Pos}(\text{VP}, t_6) \in W_{\text{Mignon \[DS\]}} \)
\( \text{Orient}(\text{VP}, t_6) = \text{ORIENT}(W_{\text{Mignon \[DS\]}}, 1) \)
Follow Mignon St.

<table>
<thead>
<tr>
<th>Time</th>
<th>Position</th>
<th>Orientation</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>( t_1 )</td>
<td>( W_{\text{Danton [AP]}}, 1 )</td>
<td>ORIENT(W_{\text{Danton [AP]}}, 1)</td>
<td>Follow Danton St.</td>
</tr>
<tr>
<td>( t_2 )</td>
<td>( W_{\text{Danton [PO]}}, 1 )</td>
<td>ORIENT(W_{\text{Danton [PO]}}, 1)</td>
<td>Cross Poitevins St.</td>
</tr>
<tr>
<td>( t_3 )</td>
<td>( W_{\text{Danton [SE]}}, 1 )</td>
<td>ORIENT(W_{\text{Danton [SE]}}, 1)</td>
<td>Cross Serpente St.</td>
</tr>
<tr>
<td>( t_4 )</td>
<td>( W_{\text{Centre Henri Piéron}} )</td>
<td>ORIENT(W_{\text{Danton [SE]}}, 1)</td>
<td>You are in front of Centre Henri Piéron</td>
</tr>
<tr>
<td>( t_5 )</td>
<td>( W_{\text{Danton [MI]}}, 1 )</td>
<td>ORIENT(W_{\text{Mignon [DA]}}, 1)</td>
<td>Turn on Mignon St.</td>
</tr>
<tr>
<td>( t_6 )</td>
<td>( W_{\text{Mignon [DS]}}, 1 )</td>
<td>ORIENT(W_{\text{Mignon [DS]}}, 1)</td>
<td>Follow Mignon St.</td>
</tr>
</tbody>
</table>

Table 2: Formulae of VP’s position and orientation as illustrated in Figure 5

A specialized module of the GRAAD that we have already developed [Moulin & Kettani 1998b] transforms these simple expressions in a more sophisticated description as follows: « You are on St André Square. Follow Danton street. You will cross Poitevins street and Serpente street. At that time, you will be in front of Henri Piéron Center. Turn on Mignon street ».

4. Validating the cognitive plausibility of GRAAD’s outputs

So far, we have seen that the spatial model that we propose is based on cognitive process (building and manipulating influence areas) and mental structures (mental maps). Unfortunately, this is not a guarantee that GRAAD will necessarily produce cognitively plausible outputs. This is why we performed an experiment involving human subjects. The main goal of this experiment was to know if routes and their corresponding natural language descriptions generated by GRAAD could be distinguished from Routes and Descriptions (RD) generated by human subjects in similar experimental situations.

We adopted a method based on the Turing test [Turing, 1950] which consists in comparing RD generated by GRAAD and RD generated by human subjects. The idea of the experiment is that if people cannot distinguish the artificial RD from the human RD, we can conclude that they are similar and equivalent. We conducted this
experiment with 20 persons of different genders, ages and professions. The experimental environment that we have chosen for our experiment is the campus of Laval University and the experimental route is the one that links two buildings: « La Pyramide de Sainte-Foy » and « Le Pavillon Bonenfant » (Figure 6). People familiar with Laval University’s campus generally know well these two landmark objects.

4.1. Collecting human route descriptions

The objective of this first stage is to collect human routes and their corresponding descriptions. We met 10 subjects, each separately, and asked him or her to answer the following three questions:

1. Could you show and describe the route to go from « La Pyramide de Sainte-Foy » to « Le Pavillon Bonenfant »? For this first question, subjects only used their knowledge about the spatial scene and landmarks that they could remember. They could not use a map of the scene nor have more information about a specific landmark. We present in Text 1 an example of a subject’s answer to this question.

<table>
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<tr>
<th>French Version</th>
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<tbody>
<tr>
<td>De la Pyramide de Sainte-Foy prenez la rue Néré-Tremblay et puis à l’intersection, prenez le chemin Sainte-Foy en direction Est. À la prochaine lumière, tournez à droite et vous entrez au campus. À la prochaine lumière tournez à droite et puis tournez à gauche à l’autre lumière.</td>
<td>Le pavillon Bonenfant est le second bâtiment à votre droite.</td>
</tr>
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</table>

1 All of these 10 subjects study or work at Laval University. We can then easily suppose that they have a mental image of Laval University’s campus and they can exploit the cognitive mechanisms of building and manipulating mental images.
From « La Pyramide de Sainte-Foy » take « Néré-Tremblay Street » and then, at the junction, take « Sainte-Foy Street » following the east direction. At the next light, turn right and you will arrive on the campus. At the next light, turn right and then turn left at the next light. « Le pavillon Bonenfant » is the second building on your right.

2. Using the map of Laval University’s campus attached in annex, can you describe the route to go from « La Pyramide de Sainte-Foy » to « Le Pavillon Bonenfant »? To answer this question, subjects could use the map to identify landmarks and their spatial and descriptive properties. We present in Text 2 an example of a subject’s answer to this question (the same subject as the one who wrote Text 1).

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<tr>
<td>De la Pyramide de Sainte-Foy prrenez la rue Néré-Tremblay et puis à l’intersection, prenez le chemin Sainte-Foy en direction Est. À la prochaine lumière, prenez la rue du Séminaire à votre droite pour entrer au campus. À la prochaine lumière tournez à droite sur la rue du Séminaire et puis tournez à gauche à l’autre lumière. Vous êtes sur l’avenue des Sciences Humaines et le pavillon Bonenfant est la seconde bâtisse à votre droite.</td>
<td>From « La Pyramide de Sainte-Foy » take « Néré-Tremblay Street » and then, at the junction, take « Sainte-Foy Street » in the East direction. At the next light, take « Le Séminaire Avenue » to your right in order to go into the campus. At the next light, turn right on « La Terrasse Street ». Then turn left at the next light. You are now on « Sciences Humaines Avenue » and « Le Pavillon Bonenfant » is the second building on your right.</td>
</tr>
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</table>

We think that these two questions allowed subjects to gradually increase their knowledge about the experimental scene and then exploit a knowledge similar to what GRAAD possesses a priori. We collected the answers to each of these questions and put them in a separate set.

4.2. Generation of artificial route description

The goal of this stage is to get a route and its corresponding description provided by GRAAD. We used the drawing tool provided by GRAAD to build the map of Laval University’s campus and to specify its spatial and descriptive attributes. We asked GRAAD to generate a route from « La Pyramide de Sainte-Foy » to « Le Pavillon Bonenfant », GRAAD generated the route and its description (Text 3).

<table>
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<tbody>
<tr>
<td>Vous êtes dans la Pyramide, sortez par la porte qui donne sur le chemin Sainte-Foy et prenez à votre gauche. Avancez sur le chemin Sainte-Foy, vous allez croiser la rue du Séminaire, tournez à votre droite et puis continuez tout droit. Au croisement avec la rue de la Terrasse, poursuivez à votre droite, vous arrivez devant le pavillon Palasis-Prince, longez-le. Allez tout droit sur la rue de la Terrasse jusqu’au croisement avec l’avenue des Sc. Humaines, prenez à votre gauche et continuez tout droit. Vous vous trouvez devant le pavillon Dekoninck, dépassez-le jusqu’au croisement avec la rue des archives et prenez à votre droite, vous arrivez à côté du Pavillon Bonenfant.</td>
<td>You are in «La Pyramide de Sainte-Foy» take the door that leads to « Sainte-Foy Street » and then turn left. Keep walking on « Sainte-Foy Street » you will cross « Séminaire Street », turn right and keep going. At the junction with « La Terrasse Street » turn right and you are now near « Pavillon Palasis-Prince », go along. Stride ahead on « La Terrasse Street » until the junction with « Sciences Humaines Avenue », turn left and keep walking. You will be in front of Pavilion Dekoninck, go along until the junction with « Archives Street » and the take your right. You will arrive near « Pavillon Bonenfant » your final destination.</td>
</tr>
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</table>

Text 3: the route description provided by GRAAD.
4.3. The comparison of HRD and ARD

The objective of this stage was to determine if HRDs and ARDs are different in any aspect. GRAAD’s route descriptions were hand-written by a colleague. We gathered it with ten other human subjects’ route descriptions. We met each of our 20 subjects separately and asked him or her the following two questions: «Do you think that some of the RD provided in annex 2 are generated by a computer? If so, would you identify these RD?». The human subjects had a reasonable amount of time (2 to 5 days) to analyze the RDs and to answer our questions.

4.4. Analysis of subjects’ answers and conclusions of the experiment

Subjects reported 41 RD as possibly generated by computer (subjects could indicate more than one ARD). Only 5 of these 41 RD were effectively generated by GRAAD and only 3 subjects pointed out and commented the ARD:

- The first subject indicated that the RD was in contradiction and does not lead to the destination (which is not true!);
- The second subject identified the artificial description and reported that it uses landmarks frequently and systematically in the formulation of the route descriptions. Although RD provided by GRAAD frequently use landmarks, we do not think that this can make them particular. In fact, most human RDs that we collected also use landmarks frequently and systematically;
- The third subject noticed that the ARD doesn’t contain enough descriptive expressions. We are currently adapting GRAAD in order to enhance this characteristic.

Considering these results, we can reasonably conclude that routes and route descriptions provided by GRAAD cannot be distinguished from any route and description provided by human beings. They are similar, equivalent and possess the same structure and content. Therefore, GRAAD’s outputs are cognitively plausible.

5. Conclusion

In this paper we described the main characteristics of a qualitative spatial model based on the cognitive concept of influence area. We discussed the cognitive basis of the notion of influence area and used this notion to formally define the notions of neighborhood, distance and orientation. We then introduced the SCM data structure that we use in our model and showed how it preserves the analogical and topological properties of space. We finally presented an experiment that demonstrated that the GRAAD’s outputs are cognitively plausible.

Now, considering that:

- the conceptual model used by GRAAD is based on cognitive process and structures;
- the form and the content of artificial descriptions and human descriptions are equivalent;
- GRAAD successfully passes Turing’s Test.

Is it possible to conclude that the model we propose is cognitively plausible? We think that this is an opened and interesting question for us and for other researchers. We are currently performing another experiment that could help us in confirming such a conclusion.

Bibliography


1 7 of these Route Descriptions were generated by subjects using the map and 3 were generated without using the map.


[Turing 1950]: A. Turing, Computing Machinery and Intelligence, 1950