Towards a Computational Semantics of Path Relations

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Abstract

We present an idea how to provide a computational semantics for path relations like *along*, *through* or *around*. Since the shape of the trajectory of a path relation is bounded by the shapes of the reference objects, an extended notion of geometrical approximations is suggested to take into account detailed shape information. Furthermore we discuss a set of features that are the building blocks of the semantics of path relations. In particular geometric features of several reference objects are evaluated to generate a single *integrated reference object*. As an example a procedural description of the semantics for *along* is presented.

1 Introduction

A lot of effort has been made to investigate spatial relations and to develop sophisticated computational (e.g [RS88, Ege91]) and cognitive models (e.g [MJL76]) that explain the appropriateness of spatial relations in specific situations. This research deepened our insight and understanding of how representations and processes of visual and verbal space are connected (e.g. [Sch94, Maa96, Her95]). From a technical point of view various applications benefit from these results since they lead to intelligent systems that build up appropriate semantics of verbal descriptions of space. From a cognitive point of view this research reveals the internal representations that are needed to understand spatial relations (e.g [LJ93, MJL76],).

Nearly all different kinds of spatial relations have been subject of research, so for example the computation of *topological* relations (e.g. "at" and "near" [Ege91]), *projective* relations ("before", "behind", "left of" etc. [RS88, Gap96]), and mixtures of both (i.e. "between" [ABHR87]). Because of their complexity little attention has been payed to a particular kind of spatial relations, the so-called *path relations* [MJL76]. Typical path relations are *along*, *past* or *around*. Sentences like "She walked along the trees" , "I went past the houses" or "I am walking around the block" are difficult to analyse because of their adverbial and temporal characteristics and therefore their groundings in time and space. The semantics of path relations do not only refer to point-like locations but also to trajectories.

In this article we focus on the idea how to select appropriate path relations for describing a spatial situation. The first idea is to solve this problem by replacing the trajectory by discrete points and then by applying the procedures for "near" or "at" (for details look at section 2). But it is possible that there is more than one trajectory for a particular path relation [VZ92].
Figure 1 depicts the geometrical representation of four houses and three different paths (A,B and C) that are representations[1] at different levels of detail of the path-description "past the houses". A method that uses discrete points from the trajectory and which relies on proximity relations would prefer path A, obviously this must not be true at all. Depending on the context also B and C are plausible representations.

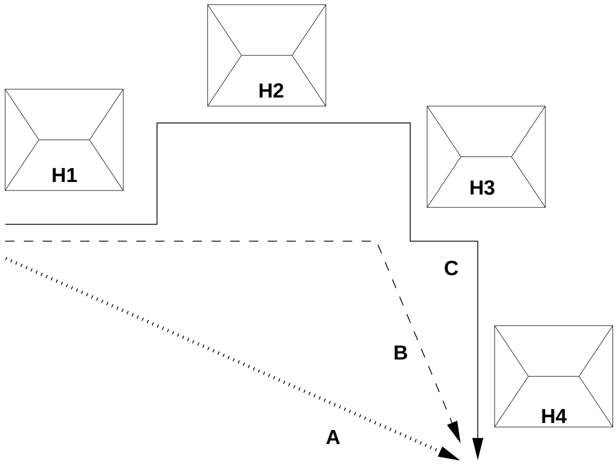

Figure 1: Problem: Three different paths for *past*

This example gives an idea of the nucleus of the problem which lies in the insufficiency of geometrical approximations that are used by the conventional approaches. Those approximations are used to represent single reference objects but this is not sufficient to cope with path relations. Instead of a reference object a path is a continuous entity. Therefore a representation is required which integrates these single objects. This representation must reflect all the necessary attributes that are needed to select an appropriate path relation. Possible geometrical integrations, are shown in figure 2. From A to C the detail level of the geometrical representation of the houses decreases and allows a simplification of the trajectory.

This paper suggests a first step towards a dynamic generation of *integrated reference objects* and their use for the selection of path relations.

The next section presents related work and then features of path relations are identified. A new approximation concept is explained that is used to define integrated reference objects and then to compute path relations. The paper closes with examples and a procedural description of *along*.

[1] Of course, there are more than these three trajectories. They were chosen only as typical examples from the infinite domain of all possibilities.

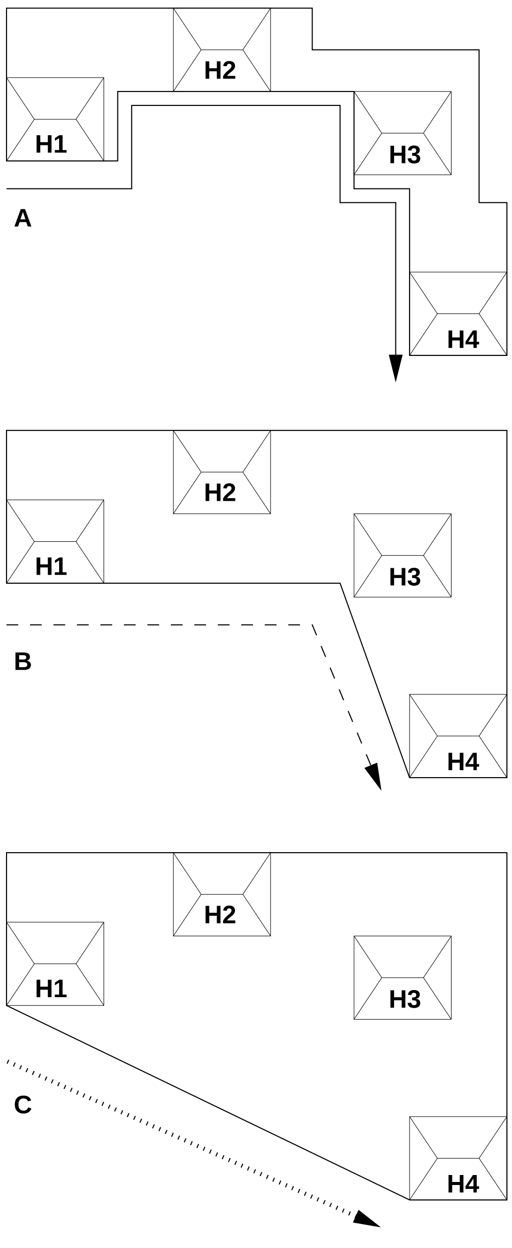

Figure 2: Solution: Three different geometrical approximations

2 Related work

This work is inspired by a paper from Landau and Jackendoff [LJ93] that focuses on the differences between "where" and "what" in spatial descriptions. The main difference between perceiving an object and describing its location is based on the level of detail of the geometrical representations that are used. Detailed information about the shape is needed to categorise an object. The use of prepositions however involves only very rough geometric properties.

Landau and Jackendoff propose for path relations that the reference object must have a significant elongation in one axis."One can travel along a river" but not "travel along a round table". They admit that path relations somehow need a more detailed geometrical representation than other prepositions do, but they do not give any further piece of advice.

In literature only little more can be found about the geometrical representations for path relations. In [ABHR87] a rough suggestion for a computational semantics of the preposition "past" is given, i.e. the halfplanes are used that are defined by the bounding rectangle which is computed with regard to the deictic or intrinsic use of "past". A similar approach is proposed for the computation of "along". A solution for multiple objects is not given and the problem of multiple trajectories is not taken into consideration.

Plausible computational and cognitive models for spatial prepositions have been developed over time. In [Gap94] a potential field is used to compute the semantics of "near" and "at". We strongly rely on these results since we try at a certain point in the computation of path relations to reduce the problem to proximity relations.

A possible application for the computation of path relations are autonomous agents that describe their visually perceived environment on the fly, e.g incremental route description (e.g. the agent MOSES [Maa96]). To accomplish this, the system must have the ability to select in a specific situation appropriate path relations.

3 Features for the semantics of path relations

Using adverbial particles implies a movement into a specific direction as demonstrated by the sentence "Frank

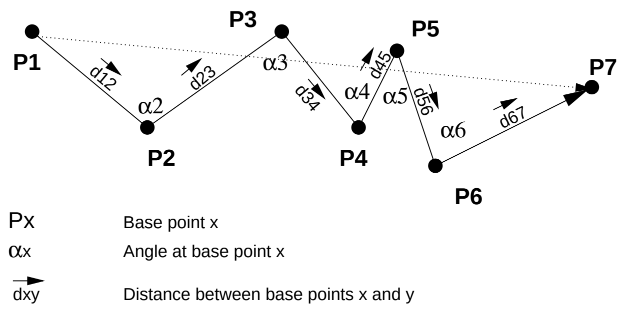

Figure 3: Properties of a trajectory

walked along the trees". Therefore path relations are grounded on a continuous geometric entity which can be described by a predicted trajectory in 2D or 3D space. In this section we describe the major features that influence the shape of a trajectory.

In general we distinguish between a moving agent, a path on which he moves and objects along that path. In the sentence above "Frank" is the agent and "trees" are the reference objects.

The trajectory itself is determined by an start- and an endpoint (P1 and P7 in figure 3). As an idealisation we suppose that a trajectory is defined by *base points* (cf. Figure 3:P1. . .P7) and each of these points has a distance to the reference objects. A change in the direction of the trajectory is only allowed between base points. This allows to distinguish between simple and complex trajectories depending on the number and relative distance of base points and the size of directional changes. Another criterion is the derivation from the main trajectory direction defined by its start- and endpoint (the dotted line in Figure 3).

The following paragraphs introduce different features that have an influence on the selection of path relations.

3.1 Size of objects

The size of objects may vary extremely. So it is possible for an ant to travel along the mountains or for a plane to follow a river. These are two extreme examples and even if most of every day use of path relations lies somewhere in between, it is obvious that all these trajectories look different and depend on the size of the objects. The size of the agent with respect to the reference objects determines how many base points a trajectory might have. Details that are smaller than the size of the agent can not be taken into account.

In order to handle the size of objects appropriately a normalised coordinate system [Gap96] has to be used.

3.2 Speed of agent

Often it is the verb that determines the speed of the agent (compare "Peter ran along the building" with "Peter strolled along the building") and influences the possible distance of the path to the reference object(s). At a higher speed the agent cannot change its direction so often and therefore the resulting trajectory has less base points. As a consequence the distance between a trajectory and reference objects is usually larger. This leads to a kind of *safety* region around the agent. After this extension the problem of handling the speed of an object is reduced to the problem of handling its size and this was explained above.

3.3 Field of visual attention

Not all parts of reference objects are visually perceived and therefore do not influence the shape and distance of a trajectory. The trajectory underlying the sentence "Peter went along the forest" is only influenced by the trees at the edge of the woods, since only those are perceived. Another important feature regards the salience of a reference objects that is considered as important for path relations (see [Maa96]).

3.4 Communicative context

Since a sentence with a path relation is communicated from a speaker to a listener, communicative context model approaches [Nei76, Lak87, Maa96] must be regarded. This includes that path relations are usually part of a communicative act. For example as part of a navigational directive:

"....turn left at the next bookshop, then *go along the park* until you pass a huge oak , there you turn left again...". Here the oak is part of a park and a landmark, where the trajectory of the path relation turns left. The approximations that are used for the path relation must reflect this issue. This shows that the goals and intentions of the speaker and listener play an important role for the exact shape of the path.

Common sense knowledge also influences the trajectory of a path relation. The sentence “Go along the houses” for example does not imply that one should go as close to the houses as possible. One should normally regard the privacy of the inhabitants and should not step onto the lawn in the front garden.

The type of the agent is another factor that changes the appearance of the trajectory. The path of a pedestrian underlies different constraints than paths of cars or planes.

4 Geometric abstractions of reference objects

The idealisations and geometrical approximations that are usually used for the computation of spatial relations [MJL76, ABHR87] are not sufficient for our purpose as shown above. The most common idealisation (following [Gap96]) are the *center of gravity*, the *bounding rectangle/box*, *lines and points* and as an important 2D representation the *base* of an object.

In addition to these very rough approximations we propose a concept of an integrated reference object that allows us to choose the abstraction level, i.e. the amount of geometrical details in the approximation, that fit best the features of the semantics of the path relation. One of the most important aspects is that we need abstract geometrical approximations for multiple reference objects. One must know which geometrical properties are relevant when referring to “houses”or “trees”. In particular if they are separated by huge gaps (see figure 1). An important observation is, that the approximations cannot be precomputed, since this would lead to a combinatorial explosion.

The abstraction techniques that we propose in the following paragraphs were designed for the use in Intellimedia-Systems [AGH+93]. They help to reduce the *cognitive load* of the viewer of multimedia documents, in the way that only the important details of the graphics are shown at a low abstraction level and irrelevant ones are suppressed in a high abstraction. In order to gain high flexibility the abstraction techniques simplify directly the underlying geometrical 3D-models. As a convenient side effect most of these geometrical abstractions also reduce

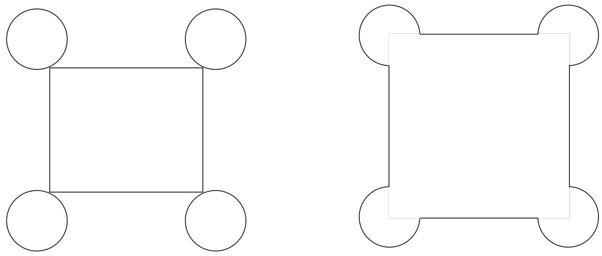

Figure 4: The abstraction of *cubes* and *cylinders*

the computational effort of the underlying representations and thus speed up all computations involved.

We regard a geometric abstraction as *simplification* with respect to an original, if it contains less *object’s parts* and if its shape consists of less *line segments* (2D) or *faces* (3D). Important attributes that should be maintained in abstraction are *axes* that indicate the objects orientation or symmetry. For a more elaborated discussion of this topic see [BK96].

4.1 Single reference objects

Two different approaches can be taken into consideration for the abstraction of single objects: The *primitives* and the *filtering* approach. The former constraints the underlying geometrical domain to consist of primitive elements, like cubes, cylinders or laminas and requires a lot of modeling effort. The advantage is that knowledge about shape properties is implicitly represented in the geometrical domain (since we know that for example a circle/sphere is round and a square/cube is not). This information can be used by an abstraction mechanism to maintain these properties in the abstraction result. However, this method is limited by the primitives that can be used, and for every primitive that is added the abstraction method must be adapted in order to handle the new primitive appropriately. Figure 4 shows an example of a simplification of a castle (cube) with four towers (cylinders).

The *filtering* approach is independent from the geometrical domain (the only precondition is that the geometrical models must consist of polygons (in 3D) or line-segments (in 2D)), no primitives are needed. Therefore it is very flexible concerning its input, but no further geometrical information of the domain is available and must be added separately (for example the axes and orientation of the objects). The filtering approach divides the object in question into several regions. All points of the polygon model in that region are replaced by one single point. Depending on the size of the region the abstraction level increases and details vanish. Figure 5 illustrates the filtering of the polygon model of a pear. Depending on the underlying

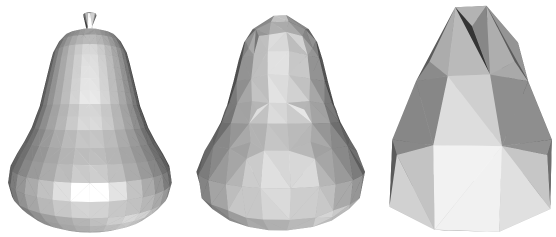

Figure 5: The Simplification of a pear

geometrical representation we are able to use both methods. For a closer look to the abstraction of primitives we suggest [Krü95, Fei85]. The filtering approach was developed by [RB93] with modifications and improvements from [BK97].

4.2 Integrated reference objects

To determine valid trajectories for a given path relation a simplified representation for a cluster of reference objects is convenient as figure 1 and 2 illustrate. Such an abstraction can be obtained by virtually closing the gaps between the single reference objects. Since the arrangement of the objects may result in a specific shape, "Gestalt" laws [Met75] must be taken into consideration thus proximity relations of objects play an important role. An implementation of a merging-operator for primitive objects can be found in the abstraction system $\mathcal{PROXIMA}$ [Krü95] (see figure 6).

Once a integrated reference object is determined, the application of methods, that were discussed in the forgoing section offer the possibility to further increase the abstraction level of the approximation.

Another implementation of these kind of simplifications can be found in the field of the automatic generalisation of buildings [Pow93]. Cartographers use these techniques to derive new maps at a higher level of detail from existing maps.

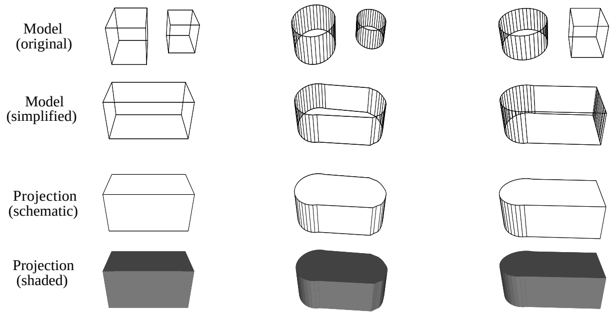

Figure 6: Merging of primitive objects

5 The path relation *along*

As an example of a path relation we present our approach in more detail for the preposition *along*.

5.1 Examples

Figure 7(a) shows different geometrical abstraction levels for a u-shaped building that we will use to illustrate the different interpretations of *along* in changing contexts.

Assume that the path of an agent from A to the door D has to be verbalised. The corresponding geometrical representation that is used to compute the path relation is shown in Figure 7(b). Since the path to the door is to be described , the door must be in the geometrical representation but the other doors must not. This example also shows, that the abstraction must be generated dynamically at run time, since it is not clear in advance which door is important for the directive.

A coarser representation can be chosen when the directive can be less detailed. In cases where the doors are not to be mentioned they are not regarded in the geometrical representation (see Figure 7(c)).

The applicability of *along* is tightly connected to the features that we described in section 3. Figure 8 illustrates the effects of the size of the agent. One would easily accept a description of agent X moving on path AB like: "agent X walks along L". Problems arise when the distance from the reference object augments. Path AD would be probably still acceptable for the selection of *along*, but not path AC.

It seems that the shape information becomes less im-

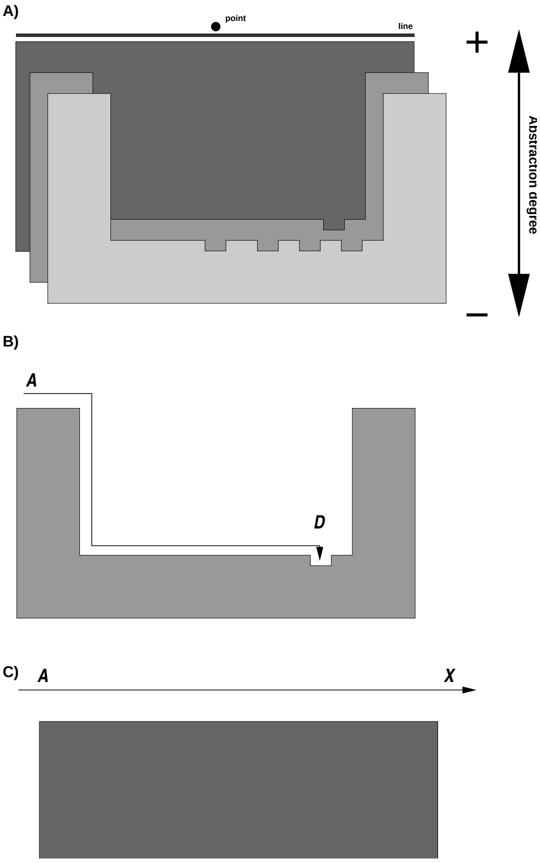

Figure 7: Different abstraction degrees of a building

portant with increasing distances. In these cases the major axes play a more important role. This seems to be the explanation why path EF is plausible, but paths EG and EH are not.

The situation changes when instead of agent X the larger agent Y is involved. Because of the agent's size, path AB is not applicable at all. In contrast to that path EH turns to be a reasonable representation of "agent Y walks along L".

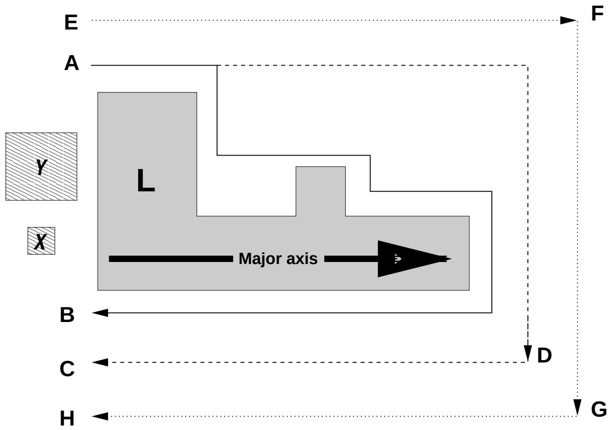

Figure 8: The size of agents influences the applicability of *along*

5.2 Procedural description

This section proposes a procedure to compute the preposition *along*. The use of the approximations we discussed above in combination with traditional computations of proximity allow a flexible handling of path relations.

Up to now we have focused on the selection of path relations. But the following procedure can also be used in reverse to analyse spatial descriptions. An application that could make use of such a procedure is an autonomous agent or robot that is navigated by linguistic expression. The task in this case is to find a trajectory that matches the given path relation.

We will now focus in detail on the selection of path relations. Nevertheless the ideas to solve the first part are similar and an implementation is straightforward.

The input to the algorithm is the trajectory, as described in section 3, and a geometrical description of the surroundings that is as detailed as possible.

The first step of the algorithm determines the relevant reference objects. We suggest to select all salient objects that are near the trajectory (cf. [Maa96]). The number of useful reference objects in a scene also depends on context information, for example on the perspective of the agent. A top-down view on the surroundings allows to select much more reference objects than a perspective view from within the scene (We sketched this problem in section 3.3).

In a second step the selected reference objects are grouped together by establishing an integrated reference object.

The third step is the abstraction step. The most plausible abstraction is computed as described in section 4.

The last step computes whether the trajectory holds for the given path relation or not. For this purpose a representative line is derived from the abstraction. We suggest to use the base/frontline of the object's side that is oriented towards the trajectory. Depending on the complexity of the trajectory, points on both lines are chosen and compared by a proximity operator [Maa96, Gap96]. The trajectory is appropriate, if all points on the trajectory are near to points on the base/frontline.

In cases of a single reference object (like a river or road) its main shape properties can be described by a trajectory. The similarity between both trajectories (reference object and path) influence the applicability of a particular path relation. Standard statistic techniques can be used to compute the difference of the shapes of the two trajectories (i.e. average distance and standard deviation) and according to a certain threshold the decision can be made.

6 Summary and future work

We presented an approach towards the computation of path relations. An extended notion of reference objects was introduced in order to overcome problems that arise from too rough simplifications. Furthermore it was shown how single objects can be grouped to a single integrated reference object.

With the help of these abstractions the computation of path relations was reduced to the application of a proximity operator.

Since this paper sketches only an idea a lot of work lies ahead. The rough linguistic analysis can be considered only as a first step and deeper investigations must follow. The abstraction operators that we introduced must be tested with and adapted to several different domains. To verify their reliability user studies should be made and evaluated.

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