SimSpace: A Tool to Interpret Route Instructions with Qualitative Spatial Knowledge

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Abstract

This paper describes our work on using qualitative spatial interpretation and reasoning to achieve a natural and efficient interaction between a human and an intelligent robot on navigation tasks. The *Conceptual Route Graph*, which combines conventional route graphs and qualitative spatial orientation calculi, serves as an internal model of human spatial knowledge on top of the robot's quantitative representation, such that humans' qualitative route instructions can be interpreted according to the model. The tool *SimSpace* then visualizes and proves the interpretation using qualitative spatial reasoning. Furthermore, *SimSpace* will generate appropriate natural feedback if a route instruction cannot be interpreted properly.

Introduction

Since almost every interactive system uses knowledge of a certain domain to communicate with users, the representation of such domain knowledge decides not only the content but also the manner of the interaction. We focus here on conversational communication between a human and an intelligent service robot (e.g. the Bremen Autonomous Wheelchair *Rolland* (Lankenau and Röfer 2001; Mandel, Huebner, and Vierhuff 2005)) on navigation tasks. One typical scenario is that a human instructs Rolland to move around in a university building with a sequence of route instructions such as "turn left", "pass by the room 1.45 on the left". Although most robots use quantitative information for navigation, such quantitative data are often simplified or even distorted by humans; instead, qualitative representation is often used for representing humans' spatial knowledge and for reasoning with and about it (cf. (Michon and Denis 2001; Shi and Tenbrink 2005)).

Considering this incompatibility of spatial representations between humans and robots, we have developed a qualitative spatial model, i.e., the Conceptual Route Graph, which serves as an internal model for natural communication with humans and for efficient mapping to the robot's quantitative representation. For the automatic interpretation of and reasoning about humans' route instructions, the tool SimSpace has been developed, in which qualitative spatial reasoning is used.

Conceptual Route Graph

Route graphs have been proposed as a common knowledge base of humans or mobile agents for navigation (Werner, Krieg-Brückner, and Herrmann 2000). They are constructed through the integration of a number of routes between different places, where the information concerning accessibility of each place is also integrated. Thus, they can be used as metrical maps to control the navigation of mobile robots in various environments. On the other hand they are used to represent humans' topological knowledge on the qualitative level while they act in space.

The Double-Cross Calculus (DCC) was introduced in (Freksa 1992) for qualitative spatial representation and reasoning using orientation information. Combining the front/back and the left/right dichotomy, the DCC may distinguish 15 meaningful qualitative orientation relations (or DCC relations), such as "front", "rightfront", "right", etc.

The Conceptual Route Graph (CRG) (Krieg-Brückner and Shi 2006; Shi and Krieg-Brückner 2008) combines the structure of conventional route graphs and the Double-Cross Calculus. A CRG is a special graph, its nodes are called *places* and edges *route segments*. Each place has a local orientation, which may be rooted in a global reference frame. Additionally, it has a set of DDC relations describing the orientation relations between route segments and places. A *Route* of a CRG is then a sequence of connected route segments. Thus, CRGs can be seen as route graphs with only qualitative information, i.e. the DCC relations.

SimSpace

SimSpace is a tool for interpreting, visualizing and proving of natural route instructions using qualitative spatial reasoning with a given conceptual route graph. The following are its two most essential functions:

- **Construction of CRGs**: One possible way of constructing a CRG is based on quantitative spatial data. SimSpace takes a well-defined quantitative route graph as input and constructs a corresponding CRG in two steps:
  – the qualification of the quantitative data with the qualifying module of the toolbox SparQ (Wallgrün et al.

2007);

  - the generalization of the qualified relations, i.e., the relations qualified from angles near 0°, 90° and 180° are assigned to those exactly from 0°, 90° and 180°, e.g., ”rightfront” to ”front”, or ”leftback” to ”back”. The generalization is necessary for three reasons: first, CRGs serve as an internal model of humans' spatial knowledge and humans tend to use abstracted information while they act in space (cf. (Sadalla and Montello 1989; Montello 1991)); second, ungeneralized relations could be too complicated for qualitative spatial reasoning; third, in most office building environments corridors are constructed orthogonally, thus such generalization retains the environment information.

- **Reasoning with CRGs**: The reasoning with CRGs is based on the following operation:

  $$Rel(ab, p) = comp\_path(shortestPath(ab, p)),$$

  which calculates the orientation relation between a place p and a segment ab through sequential compositions along the shortest path from ab to p. For example, if the shortest path from x_1x_2 to x_4 is $\{x_1, x_2, x_3, x_4\}$, the relation between x_4 and x_1x_2 can be obtained by:

  $$\begin{aligned} Rel(x_1x_2, x_4) &= comp\_path(\{x_1, x_2, x_3, x_4\}) \\ &= comp(Rel(x_1x_2, x_3), Rel(x_2x_3, x_4)) \end{aligned}$$

  Using this basic operation, other high-level operations concerning specific route instructions can be defined.

Together with the calculation module provided by SparQ and an ontology-based annotated database, SimSpace supports now a number of often used route instructions, such as ”drive straight”, ”turn”, ”drive until”, ”pass by”, etc. Through simple actions like selecting and clicking, the interpretation results of given route instructions, i.e., the planning of relevant routes or meaningful feedbacks concerning the spatial mismatches detected in the route instructions, can be proved and generated by SimSpace, respectively. For instance, the route instruction ”pass by room A and then room B”, which is known as difficult to solve with quantitative spatial computation, can be treated by SimSpace, and the following feedback will be generated, if room B is located before room A from the point of view of the start position:

”Cannot pass by room B, maybe it's now behind you?”

Conclusion

In this paper we presented our work on the modelling and reasoning of humans' natural route instructions using the qualitative spatial model Conceptual Route Graph and the qualitative reasoner SparQ. After building the qualitative spatial model from a given quantitative one, the tool SimSpace provides a set of functions to interpret and prove route instructions according to the qualitative model, and to generate clarification subdialogues in the case of inconsistency of a route instruction with respect to the model. Thus, with SimSpace it is possible to decide whether a spoken route instruction is interpretable by a qualitative spatial model. Consequently, some interpretation(s) will be presented, or adequate reasons will be generated for the further communication with the user.

A large number of route instructions given to the wheelchair Rolland in a university office building was collected in an empirical study (Shi and Tenbrink 2005). We are now using the tool SimSpace to evaluate the coverage of our conceptual model for interpreting those route instructions and to analyze the reasoning results with SparQ for reporting inconsistent situations intuitively.

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