SparQ—A Spatial Reasoning Toolbox[1]

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Abstract

SparQ is a toolbox for qualitative spatial reasoning. Interpreting reasoning in a broad sense, SparQ covers mapping information from quantitative to qualitative, applying constraint reasoning to qualitative information, reasoning about calculi, and mapping qualitative information back to the quantitative domain. The toolbox is designed for extensibility and released under the GNU GPL public license for free software.

Motivation

Qualitative spatial reasoning (QSR) (Cohn and Hazarika 2001) is the subfield of knowledge representation and symbolic reasoning that deals with knowledge about an infinite spatial domain using a finite set of *qualitative relations*. One particular aim is to model human common-sense understanding of space. Qualitative representations are compact and enable complex decision tasks. They are relevant, for instance, in human-machine interaction contexts or in applications reaching for near human-level spatial intelligence. Yet, applications that demonstrate the advantage of qualitative reasoning are rare.

This observation triggered the development of SparQ. Why is qualitative reasoning hardly used in applications? We believe that the lack of available tools significantly contributes to this dilemma. Composition tables for qualitative calculi—if available—are annoying to type, properties unclear, and reasoning algorithms are not easy to implement too. We designed SparQ as a toolbox to provide access to such techniques in an easy-to-use manner. We aim at gathering essential tools for representing spatio-temporal information qualitatively, from defining qualitative relations to inference tasks.

Qualitative Reasoning

Qualitative relations are used as symbols to represent knowledge by stating relationships of variables that range over a spatial domain. For example, the statement A `north_of` B could represent the fact that object A is located *somewhere* north of B. Qualitative relations constrain the valuation of variables. Thus, qualitative spatial reasoning is a form of constraint-based reasoning over infinite domains and it shares much of the terminology with constraint-based reasoning.

Qualitative representations are foremost characterized by the set of relations they employ. These relations and certain operations on them constitute a qualitative calculus. Using calculus operations, one is able to infer new knowledge using constraint-based reasoning (Renz and Nebel 2007). Naturally, as qualitative representations are problem-specific, a great variety of them has been developed. Using a qualitative approach within a task, some typical subtasks can be identified:

- selecting qualitative relations (task-specific)
- instantiating a calculus according to relation semantics
- (constraint-based) inference
- connecting quantitative information (e.g., used by input/ output devices) to qualitative information

Ideally, one would only need to specify qualitative relations to be used—reasoning methods would be instantiated automatically. This goal remains however subject to further research. Manual work is necessary for introducing new calculi and some properties of existing calculi have not been analyzed yet, but there already exists an extensive repertoire of qualitative calculi suitable for a great variety of tasks.

SparQ

The spatial reasoning toolbox SparQ (**Spa**tial **R**easoning done **Q**ualtitatively) aims at providing a tool collection that brings qualitative reasoning closer to applications. Currently, SparQ contains tools for

- connecting quantitative and qualitative information
- constraint-based qualitative reasoning with binary and ternary calculi
- analyzing qualitative calculi to aid design of new calculi

Users can easily specify their own calculi or they can take advantage of the growing calculi repository that comes along with the toolbox.

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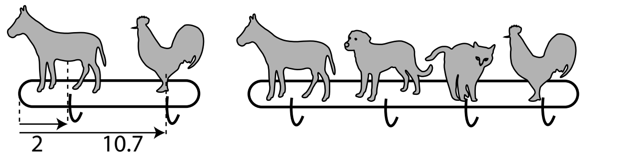

Figure 1: existing coat rack (left) and extended design (right)

A Stip Visit to SparQ

Let us consider a very simple example of how the qualitative reasoning toolbox can be applied in the context of a design task, and, by that, we glance at the main tools offered by SparQ. Suppose we are to improve the design of a coat rack for a child's room based on an existing smaller model where pegs are fixed to a wooden beam (see Fig. 1 left). There are two pegs in the existing design, one attached to the figure of a donkey, the other to the figure of a rooster. We need to add two additional pegs attached to a cat and a dog to complete the lineup from the fairy tale of the Bremen town musicians.

The design process involves finding the "right" arrangement of figures on the beam. Besides considerations subject to the eye of the designer the fairy tale poses a constraint on the placement of the cat: (1) the dog follows after the donkey, (2) the cat is positioned before the rooster.

In a computer aided design process, SparQ can be employed to formalize design constraints and to determine solutions. In our example, we use the simple Point Calculus (PC) to classify the relative, linear order of objects like the order of pegs on a beam. In Fig. 2 the calculus definition of the Point Calculus as used by SparQ is shown. As a first step, the existing design is *qualified*, i.e. the quantitative spatial arrangement extracted from the design is described in qualitative terms. The design software would send the following request to SparQ which would store the result for later use:

```
let oldDesign = qualify pc all ((donkey 2)
  (rooster 10.7))                        <ENTER>
```

The new design rules would need to be specified as constraints, we obtain `donkey < dog` and `cat < rooster`. These constraints are merged with the old design:

```
let newDesign = constraint-reasoning pc
  merge $oldDesign ((donkey < dog) (cat <
  rooster))                              <ENTER>
```

Finally, we would query SparQ for all scenarios, i.e. fully specified constraint networks that satisfy all design rules:

```
constraint-reasoning pc scenario-consistency
  all $newDesign                         <ENTER>
```

As result we obtain the 11 possible scenarios, which can now individually be quantified[1] for visualization, e.g. (cp. Fig. 1 right):

```
quantify pc ((donkey < dog)(rooster >
  dog)(rooster > donkey)(cat > dog)(cat >
  donkey)(cat < rooster))                <ENTER>
```

The resulting quantitative scenario can easily be presented by the design software.

[1] quantification in general is still work in progress

```
(def-calculus "1D Point Calculus (pc)"
  :arity           :binary
  :basis-entity    :1d-point
  :base-relations (< = >)
  :converse-operation
    ((< >) ; A<B => B>A
     (= =)
     (> <))
  :composition-operation
    (( < <  < ) ; A<B, B<C => A<C
     ( < =  < )
     ( < > (< = >)) ... )
  :algebraic-specification
    ((< ((1 ((ax 1))) < (1 ((bx 1)))))
     (= ((1 ((ax 1))) = (1 ((bx 1)))))
     (> ((1 ((ax 1))) > (1 ((bx 1)))))))
```

Figure 2: Calculus definition in SparQ

SparQ for Researchers Working in the Field

Qualitative reasoning is not a closed field of research but presents many open research challenges, e.g., understanding computational properties like, for example, whether algebraic closure decides consistency of constraint network for a given set of qualitative relations. Therefore, SparQ includes additional tools addressing researchers' needs for analyzing existing or developing new calculi. For example, an algebraic reasoning tool supports computation of composition tables on basis of an algebraic relation specification.

Summing Up and Looking Ahead

SparQ is a toolbox for qualitative spatial reasoning that aims at providing ready-to-use tools for anyone interested in using qualitative methods. Development is driven by the motivation that bringing QSR to applications is a crucial, urging, challenging, but rewarding step in this field of research.

Qualitative spatial reasoning is a research field peppered with many open questions. SparQ also offers tools for researches that can be used for validation of new theories or may even trigger new ones.

Reasoning is more than constraint-based inference. In future versions we would like to feature a universal approach to mapping qualitative information to the quantitative domain. Also, we like to support retrieval tasks using qualitative arrangement information, for instance, in the area of geographic information systems.

References

Cohn, A. G., and Hazarika, S. M. 2001. Qualitative spatial representation and reasoning: an overview. *Fundamenta Informaticae* 46:1–29.

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