Towards a Comprehensive Understanding of Context in Conceptual Spaces

Carsten Keßler[1] and Martin Raubal[2]

[1] Institute for Geoinformatics, University of Münster, Germany
carsten.kessler@uni-muenster.de
[2] Department of Geography, University of California at Santa Barbara, USA
raubal@geog.ucsb.edu

1 Introduction and Motivation

Language is inherently connected to cognition (Herskovits, 1986; Lakoff, 1987). Accordingly, natural language communication about space (Peterson, Nadel, Bloom, & Garrett, 1996), such as navigation instructions, or place descriptions and comparisons, are grounded in human spatial cognition. In order to allow for the automatic generation and recognition of spatial language, a correspondingly grounded computational model is required. A formalization of conceptual spaces (Gärdenfors, 2000)—sets of quality dimensions with a geometrical structure—provides such a model. Conceptual spaces have proven useful for the representation of concepts and entities, for similarity measurement, and the identification of prototypes. The account for context in this model, however, is limited to the assignment of different weights to dimensions and to the shift of relative terms, such as *large* or *narrow,* along quality dimensions depending on the frame of reference. The objective of this research is to extend the notion of context in conceptual spaces to enable the formal representation of *situation-dependent concept modifications* and focus shifts of agents.

To illustrate the contextual aspects we focus on here, consider the following example: A conceptual space representation of historical buildings has been developed, with information such as building age, architectural style, and historical importance. Using this knowledge base, a context-aware tourist guide is developed with two specific functionalities: (1) the temporal modification of the conceptual space via external knowledge, e.g., adapting the knowledge base to special events such as construction works; (2) the shift of focus within the space, e.g., providing personalized information tailored to a specific user. In the following, we will introduce extensions to the context model for conceptual spaces to enable such functionality.

2 Conceptual Spaces and Context

The notion of *conceptual space* was introduced as a framework for representing information at the conceptual level (Gärdenfors, 2000). Conceptual spaces can be utilized for knowledge representation and sharing, and support the paradigm that concepts are dynamical systems (Barsalou, 2003). A conceptual space is a set of quality dimensions with a geometrical or topological structure for one or more domains. Domains are represented through sets of integral dimensions, which are distinguishable from all other dimensions. For example, the color domain is formed through the dimensions hue, saturation, and brightness. Concepts cover multiple domains and are modeled as n-dimensional regions. Every object or member of the corresponding category is represented as a point in the conceptual space. This allows for expressing the similarity between two objects as the spatial distance between their points.

Conceptual spaces can be formalized as vector spaces (Raubal, 2004). Formally, a conceptual vector space is defined as $\mathbf{C}^n = \{(c_1, c_2, \ldots, c_n) \mid c_i \in \mathbf{C}\}$ where the c_i are the quality dimensions. Vector spaces have a metric and therefore allow for the calculation of distances between points in the space. This can also be utilized for measuring distances between concepts (Schwering & Raubal, 2005). In order to calculate these *semantic distances* between instances of concepts, all quality dimensions of the space must be represented in the same relative unit of measurement. Assuming a normal distribution, this is ensured by calculating the z scores for these values (Devore & Peck, 2001). For specifying different contexts one can assign weights to the quality dimensions of a conceptual vector space. This is essential for the representation of concepts as dynamical systems, because the salience of dimensions may change over time. $\mathbf{C}^n$ is then defined as $\{(w_1c_1, w_2c_2, \ldots, w_nc_n) \mid c_i \in \mathbf{C}, w_j \in \mathbf{W}\}$ where $\mathbf{W}$ is the set of real numbers.

3 Contextual Space Modifications and Focus Shifts

Although the described notion of context based on weights is useful and intuitive, it does not allow for external, i.e., contextual, modifications of the conceptual space. Building on the formalization of conceptual spaces introduced in (Raubal, 2004), we transfer the idea of context rules (Keßler, Raubal, & Janowicz, 2007)—rules that change the knowledge base under given preconditions—to conceptual spaces. An external context can consist of a number of rules *R* of the form

$$R : condition \longrightarrow \langle\{\pm c_i, \ldots, \pm c_n\}, C^n\rangle$$

where the activation condition causes the addition (+) or removal (–) of a dimension c to (or from) the conceptual space C^n. Note that a dimension c can also be a multidimensional domain of its own. Modifications of this kind require a recalculation of the z-scores for all dimensions to ensure that the same relative scale of measurement is applied for calculations of semantic distance. This mechanism allows for the augmentation of the historical buildings knowledge base with additional information.

The existing notion of context in conceptual spaces allows for the relative interpretation based on the entities represented in the space. We propose an extension to this idea by taking the user's conceptual space into account to enable a relative interpretation based on external knowledge. For example, an architect using the tourist guide will have a fine-grained knowledge of architectural styles of the buildings he visits, which can be mapped to the potentially less detailed dimension in the system's conceptual space. To enable this, we propose a re-segmentation S and re-weighting of the conceptual space's dimensions. For every affected dimension c, a number of labeled segments s, such as architectural epochs, are defined:

$$S(c) = \{s_i, \ldots, s_n\}, s = \{v_{min}, v_{max}, label\}$$

where every segment consists of a minimum and maximum value on the dimension, and a label. It is important to note that these labels, as well as the named domains, are based on natural language. Additionally, this mechanism can be used to recognize user expertise: the more fine-grained the user's understanding of a domain is compared to the system view, the more emphasis should be put on this domain when presenting information to this particular user. The corresponding emphasis value can be used to adjust the dimensions' weights to a specific user's knowledge:

$$Emphasis(c) = \frac{|S_{user}(c)|}{|S_{system}(c)|}$$

4 Discussion and Outlook

We presented initial ideas for the extension of context in conceptual spaces. The notion of context rules was transferred to conceptual spaces and a novel approach to recognize user knowledge based on domain segmentations was demonstrated. The next steps for this research comprise an integration of the outlined ideas within conceptual vector spaces and the application to an actual dataset. Moreover, the question of how to automatically derive context rules and the scales for re-segmentation will be of importance for practical applications.

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