When people refer to a location in natural language terms, they use a variety of cognitive spatial reference frames to put this location into perspective [7]. The same place can e.g. be expressed in terms of a speaker centered, object centered or absolute frame of reference, and in a way that accounts not only for the inherent spatial vagueness, but also for the geometry of figure and ground objects [16]. For example, the expression “in front of” refers to a fuzzy location of different shape and size depending on whether the ground object is a church or a spoon on a table. Furthermore, the same location may be translated to “left of” when taking the observer as a ground object. In everyday communication, people effortlessly translate between these perspectives in order to understand what a speaker means [8]. While the different types of cognitive reference frames and their relevance for different language cultures have been studied in considerable depth [12], we still lack models that can be used to actually transform a geometric representation from one cognitive perspective to another [2,14,10,17], and thus to approximate the location that a natural language expression actually refers to [3]. We suggest one reason for this is that current Geographical Information Systems (GIS) are based on crisp reference systems [1], while cognitive reference frames require transformations that can take into account fuzzy locations, translations, rotations and scalings.

![Fig.1: How to use neural field transformations in geographic maps?](image)
Such transformation models can be inspired from *neural fields* [13,5] which are used in robotics and neural science to represent approximate relative locations in terms of arrays of interconnected firing neurons [9]. Inside a neural field, location, distance, direction (angle) and other geometric properties are not a result of crisp measurement, but of the way how neurons in this field are interconnected. For example, in Fig. 1a, the authors of [9] have wired two such fields together to transform a fuzzy absolute one-dimensional position (target field) into a fuzzy object centered position, relative to a fuzzy reference position (reference field). In the resulting field, the dotted center line represents the ”origin,” i.e., the fuzzy location of the reference field, and the peak shows that the target location is “left of” the reference field. How can we apply such a method to describe the spatial configuration in a geographic map, such as the one in Fig. 1b?

![Image](image-url)

(a) The tree is to the right and in front of the observer (egocentric relative).
(b) The tree is to the East of the observer (egocentric absolute transformation).
(c) The tree is S-E of the house (allocentric absolute transformation).
(d) The tree is to the left and in back of the house (intrinsic transf).
(e) The tree is to the right and in the back of the house (deictic transf.)
(f) The tree is to the left and in front of the house (retinal transformation).

**Fig.2:** Fuzzy transformations of tree with respect to observer and house.

The trick underlying this method is that the projection takes into account all combinations of fuzzy target and reference positions to determine the relative fuzzy position in the object-centered field. We propose to mimic this behavior with *fuzzy vector spaces* [6,11,18], which allow us to compute transformations based on fuzzy translations, rotations and scalings. Using this method, we have modeled 6 well-known types of cognitive spatial reference frames [4,7] in terms of fuzzy transformations, and applied them to the geographic map with an observer, a house and a tree (see Fig. 2). The fuzzy location of the tree can now be expressed relative to the positions, alignments and sizes of the observer and the house, without any need of prior discretization. The coordinate systems in Fig. 2 express relative frames of reference, with the
origin denoting either the observer or the house, and the vertical/horizontal axes expressing either Front-Back/Left-Right or (absolute) North-South/West-East directions. Note that the size, shape and location of the tree is transformed relative to the location, size and shape of the ground objects.

Since spatial reference systems and their transformations are fundamental for GIS [15], we suggest that being able to compute cognitive transformations may lead the way towards a Neural GIS. This is a new kind of GIS without a crisp geometry that effectively allows taking human spatial perspectives and computing with locations described in natural language texts. In a neural GIS, a coordinate field denotes fuzzy positions and directions relative to a particular cognitive reference frame, and transforming and intersecting fields allows checking to what degree spatial expressions apply.

References

