Attention and Population Coding in Spatial Language

Terry Regier
University of Chicago

Laura Carlson-Radvansky
University of Notre Dame

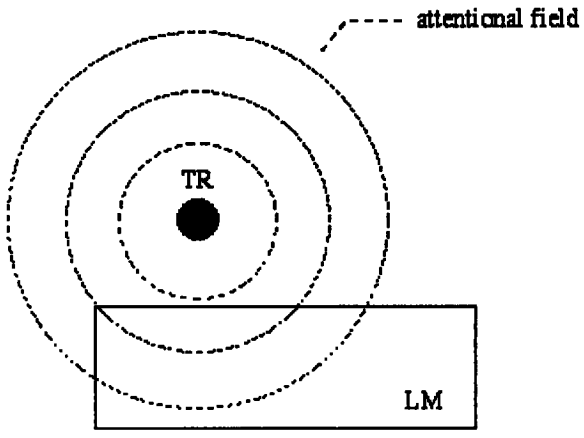
This work grounds the linguistic categorization of space in aspects of visual perception. Specifically, it grounds the structure of the linguistic spatial category "above" in processes of attention and population coding.

We begin by experimentally demonstrating that empirically collected "above" acceptability judgments show two effects of the spatial relation between objects. In particular, these judgments are affected both by the *center of mass* orientation, which is the orientation of the imaginary line connecting the centers of mass of the two objects, and by the *proximal* orientation, which is the orientation of the imaginary line connecting the two objects where they are closest. Having demonstrated these effects, we then present two competing models of "above" acceptability judgments. The first of these is the PC (Proximal and Center of mass) model, which embodies these effects as mechanisms – it predicts "above" judgments as a linear function of the degree of alignment of each of these two orientations with upright vertical. The other model is the AVS (Attentional Vector Sum) model, which is independently motivated by two considerations. The first consideration is that the apprehension of spatial relations requires the focus of *attention*. Logan (1994) has demonstrated that spatial relations between objects are not pre-attentively perceptible, but are rather perceived only after attention is fixated on the objects. The second consideration is that in some neural subsystems (e.g. monkey motor cortex, Georgopoulos et al., 1986; human motion perception, Wilson & Kim, 1994), overall direction is represented as the *vector sum* of a set of constituent directions. Georgopoulos et al. examined a population of directionally tuned cells in monkey motor cortex, immediately before the monkey was about to move its arm in a particular direction. They found that the direction of arm motion was accurately predicted by a vector sum over the population of cells as a whole:

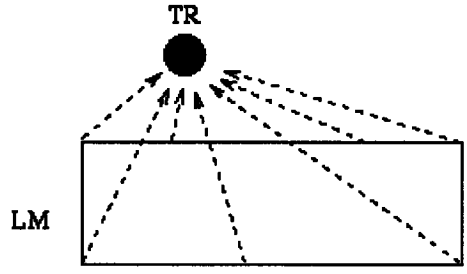
$$\sum_{i \in population} a_i C_i$$

Here, a_i is the activity of cell i, and C_i is the preferred direction of cell i.

The AVS model brings together these two apparently unrelated observations, concerning attention and population coding. In the model, an attentional beam is focused on the located object (see (a) below). This attentional beam is gaussian in shape, following empirical observations that suggest a roughly gaussian visual attentional spotlight (Downing & Pinker, 1985; LaBerge & Brown, 1989). Vectors, rooted at each point on the boundary of the reference object, point toward the located object (see (b)). Different points on the reference object will receive different amounts of attention, depending on their distance from the located object. Given this attentional beam, and these vectors, the AVS model takes an *attentionally weighted vector sum* of all vectors, weighted by the attention paid to the root of each vector. Thus, in this model, a_i is given by the amount of attention paid to the root of vector i, C_i is given by the orientation of vector i, and overall direction is computed using the same vector sum equation we have already seen. The overall resulting direction is then compared with upright vertical.



(a)



(b)

We show that the AVS model exhibits the two effects that were deliberately built into the PC model; that it provides a closer fit to the data than the PC model or related competitors; and that it makes novel, substantiated predictions concerning the effects of distance on "above" judgments. We draw two conclusions: that the structure of linguistic spatial categories may be explained in terms of independently motivated attentional and perceptual processes; and that effects need not be directly reflective of mechanisms.

References

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