

Abstract

The problem of coordinating mental structures with physical ones continues to be an active topic of study in cognitive science, especially in the field of spatial cognition, spatial navigation, and in attempts to solve the binding problem in mental representations. Cognitive scientists generally refer to two distinct types of spatial representations: metric and conceptual. By merely posing different representations of space, we cannot fully address the problem of how a spatial representation is coordinated with physical space. We propose that a referential system, such as the indexing mechanism in visual processing, is critical for coordinating mental space and physical space. Theoretical and empirical support for this referential mechanism will be discussed, as well as how this mechanism might be the crucial link for connecting mental space to physical space.

Introduction

Traditionally, spatial cognition is characterized by a conceptual space that represents a metric space. This description of two spaces lacks an important element: the manner in which they refer to each other. **Our primary goal is to address the question of how cognitive processes coordinate mental space with physical space.**



Our intuition of space is enriched by experimenting with material objects, owing to the fact that metrical experiences, which spatial intuition would not be able to acquire by itself, are connected with these objects. Thus we become acquainted with the metrical properties of forms with which we have long been familiar, such as the straight line, the plane, and the circle. Again it is experience, as history testifies, which has first led to the knowledge of certain geometrical propositions... (Mach, 1959, p. 193)

...sight-sensations do not make their appearance alone, but are accompanied by other sensations. We do not see optical images in an optical space, but we perceive the bodies round about us with their many and varied sensible qualities. Deliberate analysis is needed to single out the sight-sensations from these complexes. (Mach, 1959, p. 195)

Physical knowledge is characterized by the fact that concepts are not only defined by other concepts, but are also coordinated to real objects. This coordination cannot be replaced by an explanation of meanings, it simply states that this concept is coordinated to this particular thing. [...] It is not the concept equality of length which is to be defined, but a real object corresponding to it is to be pointed out. (Reichenbach, 1958, 14-16)

Types of Space

Schematic-Conceptual Spaces

By means of inclusion, the mind emulates qualitatively quantitative aspects of physical space, such as its geometry. **Most qualitative spatial reasoning occurs in schematic or conceptual spaces** (Bennett, Cohn, & Isli, 1997); for example, by visualizing inclusion trees or by nesting objects inside "larger" objects. Visualization, however, may be merely a phenomenological shortcut to emulate metric structures by putting to use self-generating spaces that are conceptual in nature. For example, although graphs have more quantitative information, they are conceptual representations. More importantly, **there is no way to determine the volume or containment capacity of a conceptual space** (e.g. the Internet as a virtual space).



Metric Spaces or Spaces *Strictu Sensu*

In metric space, there must be a function that calculates distances between points and preserves the triangle inequality. The geometry and topology of a space determines how to compute distances. **All metric spaces are containment spaces in the sense that they have a specific way of calculating distances regardless of what one "puts inside them"** (e.g., Riemannian or Euclidian spaces). Humans share metric representations of space with animals, such as the **representations animals use in navigation** (Gallistel, 1989, 1998) and **magnitude representations** (Gallistel & Gelman, 1992). These are basic brain operations for recognizing numerosity with dedicated and innately determined neural circuitry (Dehaene, 1997; Leslie, Gallistel, & Gelman, 2007).

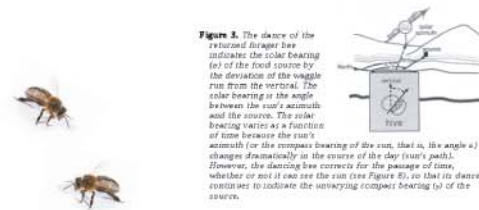


Figure 3. The distance of the retinal target bee indicates the solar bearing (α) of the food source by the deviation of the waggle run from the vertical. The solar bearing is the angle between the sun's azimuth and the source. The solar bearing varies as a function of time because the sun's azimuth (or the compass bearing of the sun, that is, the angle α) changes dramatically in the course of the day (sun's path). However, the dancing bee corrects for the passage of time, whether or not it can see the sun (see Figure 8), so that its dance continues to indicate the unvarying compass bearing (α) of the source.

(From Gallistel, 1998)

Objects: The Interface between Theoretic and Physical Spaces

Conceptual and metric spaces must interface, for example, when we interact with physical space with the help of mental representations. Conceptual spaces can be described using categories and quantifiers that range over objects or events, but metric spaces require information about distances within a geometrically and topologically defined space.

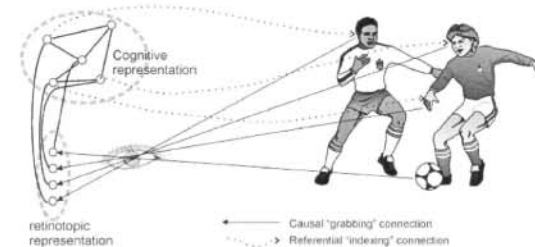
Thus, we return to the question: **how can our conceptual representation of space interface with our metric representations and how does this interface make contact with the world?** We propose that an **indexical or referential mechanism links these two spaces via objects.**

Object-Based Attention

Interacting with our environment requires us to identify and keep track of individual objects in a visual scene. **Objects are thought to provide the organizing structure of cognition and attention** (Feldman, 2003). Many studies support an **object-based theory of attention**, where the visual system selects an entire object for representational processing rather than its individual features (Scholl, 2001). **Object File Theory** is one account for the construction of such descriptive representational units during visual processing (Kahneman, Treisman, & Gibbs, 1992).

Visual Indexes

A mechanism in early vision that facilitates object-based perception is a **visual index**. **Visual Indexing Theory describes a data-driven perceptual connection from objects in the world to their mental representations** (Pylyshyn, 1989, 2001). This mechanism has been tested through Multiple Object Tracking, where observers track several moving objects among identical distractors (Pylyshyn, 2001; Pylyshyn & Storm, 1988). These preconceptual proto-objects are simply identified as individuals, also called the "numerical identity" (Xu & Carey, 1996). **Attention may interact with visual indexes to build detailed representations of the referenced objects by binding object features into an object file** (Treisman, 1998).



(From Pylyshyn, 2001)

Conclusion

Visual Indexing Theory and Object File Theory together may explain the connection between visual perception and cognition, and thus provide a framework for the representation of space. **We believe that referential systems like visual indexes are critical for the coordination of mental and physical spaces because they describe automatic perceptual processes that link external objects to their mental representations.** Further research should examine the implications for this type of referential link.

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