Embodied Models

Work in the embodied cognition paradigm has criticized existing work in semantics (e.g. Barsalou 2008; Bergen 2012), but primarily addresses Fodorian ”language of thought”-based semantics. In this paper, we argue that a formal model-theoretic semantics can be extended to incorporate embodiment by establishing relations between an amodal mental model and locations in a mental model of space. Specifically, we present a view of model theoretic semantics that incorporates an Embodied Model E that includes spatial reference points. We argue that our double model architecture offers the potential for integrating formal and embodied approach and new perspectives for gesture, sign language, and metaphor.

Double Models: Assume that F is an algebraically complete model like the ones assumed by Montagovian approaches to semantics (Montague, 1974) associated with a natural language interpretation function $[\![—]\!]$. We define an embodied model grounding F as a triple $M = \langle E, F, C_{FE} \rangle$ with the following properties: E is a set of subspaces of the three dimensional Euclidean coordinate space (We assume the Euclidean nature solely for ease of presentation). In addition, there is a correspondence $C_{FE} : F' - > E$ with $F' \subseteq F$ mapping some entities to their respective spaces (cf. Klatzky et al. 2012). We assume that, at least, the speaker and other objects the speaker perceives are always represented in both E and F: For any object o the speaker perceives, $x \in E$ is the object representation of o in F (a single atom), and $C_{FE}(o)$ is the space o occupies in the three dimensional space. The spatial locations F are isomorphic to the locations of the signing/gesturing space surrounding the speaker.

Gesture: Barsalou (1999) argues for a mental process that can *construct specific simulations of an entity or event in its absence*. In the double model architecture, entity construction amounts to a) (optionally) adding an object o to F and b) establishing a new mapping $C_{FE}(o)$ that assigns a space to o. We describe three uses of gesture that are illustrated by means of the phrase *cake* in (1). We state the context change potential using embodied models.

(1) I made a/that *cake*. The/that *cake* took two hours.

Space Assignment:Speaker points at a spatial location that uniquely identifies a space $e \in E$ with no cake $x \in F$ has $C_{FE}(x) = e$.
Update M by restricting E to those models containing at least one cake x, and adding for one cake the pair $\langle x, e \rangle$ to C_{FE}.

Deictic Reference:Speaker points at a cake or a spatial location e, where at least one cake $x \in E$ has $C_{FE}(x) = f$.
$[\![\text{cake} + \text{G}]\!] = \lambda x.C_{FE}(x) = f$

Gestural Attribution:Speaker makes a non-pointing gesture (e.g. a path or shape gesture) g adds a presupposition that the referent of $[\![\text{cake}]\!]$ has a property p with $C_{FE}(p) = g$

Counterfactuality: We assume that a set of possible worlds is part of F, and the each object o in F is located in one possible world, but can have counterparts in other possible worlds (Lewis, 1986). Objects mapped to E need not be part of the actual world @. However, C_{FE} must respect the relative spatial positions for objects occupying the same world. Consider in this light speech reports in Sign Languages (e.g. (Zucchi, 2012)) with example (2) from ASL: During the report the speaker shifts his body as indicated by the overline. We interpret the body shift as assigning John a spatial location, i.e. establishing C_{FE}(John). Within the report, further positions are then relative to John, e.g. I indicated by pointing at John's space and GO by pointing away from John's space.

(2) JOHN TELL MARY $\overline{\text{I WANT GO}}$
John told Mary that he wants to go.

Metaphor: Spatial metaphors permeate language and affect gesture. We consider the example of temporal metaphors. Núñez and Sweetser (2006) show that Aymara expresses tense spatially with the past = front and future = back, rather then with the future = front and past = back as most languages do. E.g. while in English *the year behind us* is past and *the year ahead of us* is future, in Aymara *nayra mara* (lit: 'front year') is the past, and *qhipa mara-na* ('back year-in') is the future. Núñez and Sweetser furthermore show experimentally that Aymara speakers use front pointing gestures for past and back pointing gestures for future.

We asssume that for spatial prepositions are interpreted as spatial vectors in Euclidean space within F (Zwarts and Winter, 2000). For the spatial uses, C_{FE} is subject to a homomorphism condition: If two dots x and y are related by vector $\vec{v}$, than $C_{FE}(x)$ and $C_{FE}(y)$ are be related by a corresponding vector $C_{FE}(\vec{v})$ that has the same front-back direction. For times t, we assume that simulation mappings can be established and that always $C_{FE}([\![now]\!])$ correspond to the speakers location. So, if another time t is associated with a space $C_{FE}(t)$, it will be either in the front or back of the speaker or overlap with the speaker. Then the fact that temporal gestures reflect the spatial temporal metaphor, provides evidence that the homophorphism requirement is extended to mappings of times: the temporal preposition *front* across languages must also be mapped to the (positive) front space, and *back* must correspondingly mapped to the (negative) back space.

Further Applications: The mapping from F to E associates objects with spatial locations, directions with vectors, and actions with spatial transformations. Perception and motor planning must access the same spatial representations. Pulvermüller (2013) sums up neurological data from brain lesions and activation in fMRI data as establishing an overlap betwen *category-specific semantic areas with sensory and motor areas*. We propose to explain these results within the double model architecture.

In sum, we propose that the double model architecture allows an extension of model-theoretic semantics that encompasses at least some key facts underpinning the embodied cognition approach.

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