Between CONTACT and SUPPORT: *Introducing a logic for image schemas and directed movement*

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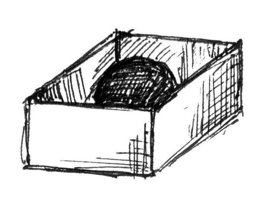
Abstract

Cognitive linguistics introduced image schemas as a missing link between embodied experiences and high-level conceptualisation in language and metaphorical thinking. They are described as the abstract spatiotemporal relationships that function as conceptual building blocks for everyday concepts and events. Although there is increasing interest in the area of cognitively motivated artificial intelligence, where image schemas are suggested to be a core piece in the puzzle to model human-level conceptualisation and reasoning, so far rather few formal logical approaches can be found in the literature, in particular regarding attention to the dynamic aspects of image schemas. A fundamental problem here is that the typical mainstream approaches in contemporary KR do not map well to various scenarios found in image schema modelling. In this paper, we introduce a spatiotemporal logic for 'directed movement of objects,' with the aim to model formally image-schematic events such as BLOCKAGE, CAUSED_MOVEMENT and 'bouncing.'

Image Schemas

Embodied cognition states that all cognition occurs as a consequence of the body's sensorimotor experiences with its environment [10]. Within this framework the theory of image schemas was introduced as a link between embodied experiences and mental representations [5, 8]. Image schemas may be described as spatiotemporal relationships between objects and their environment [7]. Commonly investigated image schemas are concepts such as CONTAINMENT, SUPPORT and SOURCE_PATH_GOAL. As natural language understanding remains one of the major obstacles in the advancement of artificial intelligence, there has been an increased interest in utilising image schemas as a stepping stone towards simulating human cognition through formal representations. The idea being that underlying our concepts are image-schematic skeletons. For instance, a cup can be abstracted to the image schema CONTAINMENT. This level of reasoning can be applied on all levels of conceptualisations. Formalisations of image schemas could have an impact for e.g. commonsense reasoning, natural language understanding and computational concept invention.

(abstraction)



CONTAINMENT

Some Problems to Overcome when Formalising Image Schemas

1. Image schemas are rarely clear-cut notions in themselves, but appear as networks of closely associated relationships.
2. Image schemas are, by definition, generic conceptual building blocks; however, they also function as building blocks for each other.
3. Image schemas are not exclusively spatial, but go through dynamic transformations.

Introducing ISL^M: A Logic for Image Schemas

As spatiotemporal relationships any formalisation needs to deal with a *spatial dimension* and a *temporal dimension*. Likewise, as they are described as relations between objects and their environment a *movement dimension* is also required. ISL^M is built on the following calculi:

The Spatial Dimension

RCC

Region Connection Calculus

The well known Region Connection Calculus (RCC) has been used extensively in QSR [2].

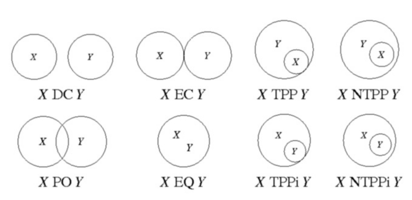


Figure 1: The eight Region Connection Calculus representations.

The Movement Dimension

QTC

Qualitative Trajectory Calculus

[4]'s QTC is here simplified into:

- if object O_1 moves towards O_2's position: $O_1 \rightsquigarrow O_2$
- if O_1 moves away from O_2's position: $O_1 \hookleftarrow O_2$,
- while O_1 being at rest with respect to O_2's: $O_1 \,|\!\circ\, O_2$

The Temporal Dimension

LTL

Linear Temporal Logic

While the temporal dimension needs attention for future work, for now we settle with traditional LTL [6]. As is standard, we can define the following derived operators:

- $F\varphi$ (at some time in the future, φ) is defined as: $\top U \varphi$
- $G\varphi$ (at all times in the future, φ) is defined as: $\neg F \neg \varphi$

Together the three calculi provide an expressive language by which spatiotemporal relationships such as those found in image schemas can be formally modelled.

Formalising Image Schemas: The *Two Object* Family

Image schemas are fine-tuned in cognitive development and exists on several different levels in language [9, 1]. Therefore, one of the central ideas of ISL^M is to formally model image schemas as a hierarchical structure that inherits previous information. In previous research [3], we looked at how the SOURCE_PATH_GOAL image schema, capturing movement, could be structured in a hierarchical family ranging from simple MOVEMENT_OF_OBJECT to increasingly complex scenarios such as REVOLVING_MOVEMENT. To complement the movement family we here introduce the different relationships between two object, the Two Object family (see Figure 2). One of the most generic relationships between two object is CONTACT in which two objects are physically touching.

$$\textsc{Contact}(O_1, O_2) \leftrightarrow EC(O_1, O_2)$$

This is strongly related to the notion of SUPPORT. In completion SUPPORT entails both vertical orientation and force, but there are also weaker forms of SUPPORT. For instance, a plank that *'leans against a wall'* also captures a form of SUPPORT, or to *'offer support to a friend in need.'* The Two Object family branches out by borrowing image-schematic components from VERTICALITY (above) and ATTRACTION (force), and when merged they construe the classic notion of SUPPORT.

$$\textit{Above}\text{-}\textsc{Support}(O_1, O_2) \leftrightarrow EC(O_1, O_2) \wedge \textit{Above}(O_1, O_2)$$
$$\textit{Force}\text{-}\textsc{Support}(O_1, O_2) \leftrightarrow EC(O_1, O_2) \wedge \mathsf{forces}(O_1, O_2)$$

$$\textsc{Support}(O_1, O_2) \leftrightarrow EC(O_1, O_2) \wedge \textit{Above}(O_1, O_2) \wedge \mathsf{forces}(O_1, O_2)$$

THE TWO-OBJECT FAMILY: **an excerpt from the extended image schema family of relationships between two objects**

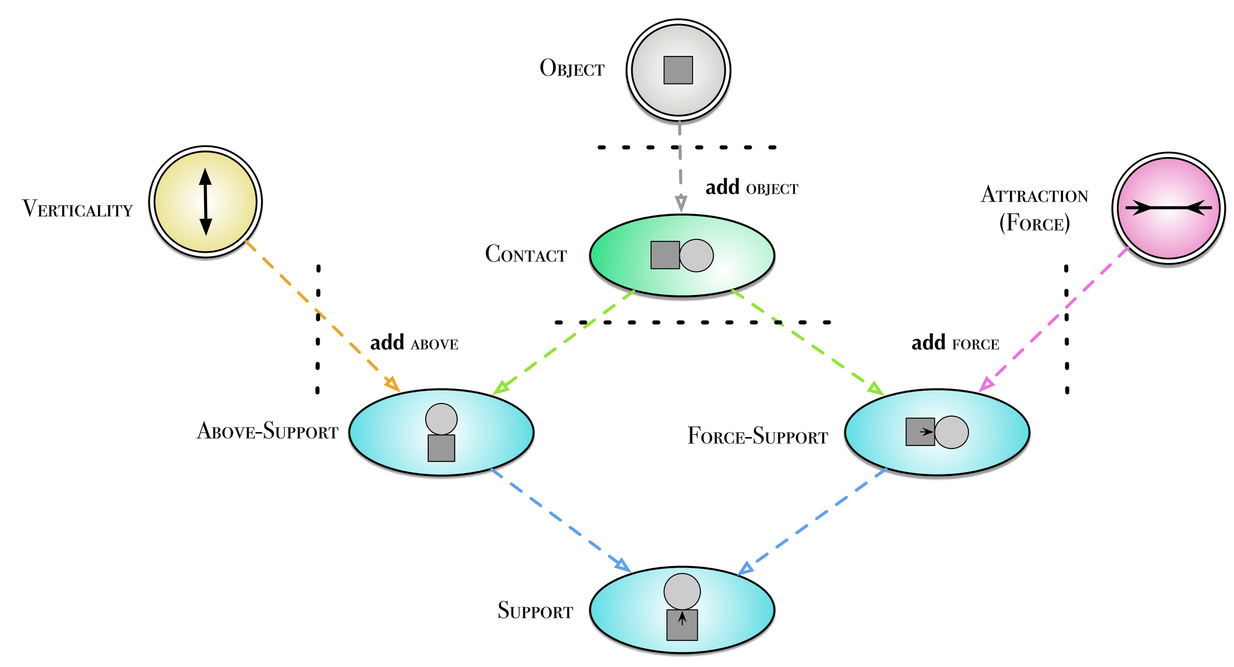
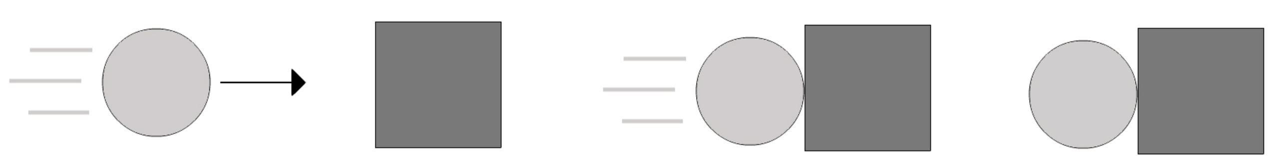


Figure 2: The Two Object Family: Hierarchical structure of some of the image schemas involving two objects.

As combinations of image schemas model increasingly complex scenarios and image schemas, the Two Object family can be combined with other image schemas (such as the mentioned PATH family) to describe more complex image schemas, events and more complete conceptualisations.

Modelling Simple Events

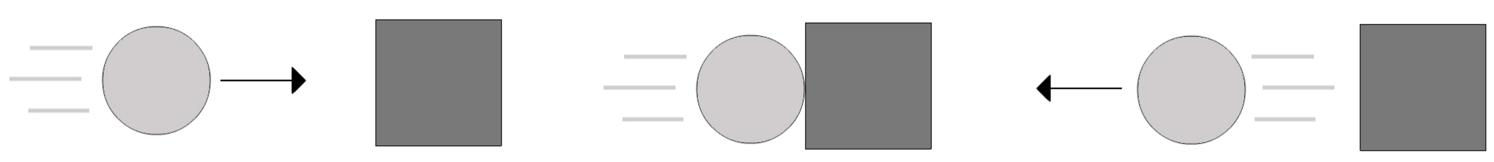
In the paper we look closer at the complex image schemas BLOCKAGE, CAUSED_MOVEMENT and the event 'bouncing' and using ISL^M to formally break down the different scenarios into the involved image schemas. As a small demonstration we here present BLOCKAGE and bouncing:



1. $\text{On\_Path\_Toward}(O_1, O_2) = (O_1 \rightsquigarrow O_2 \wedge DC(O_1, O_2))$ ((a) O_1 on PATH toward O_2)
2. $\text{Blocked\_By}(O_1, O_2) = (O_1 \,|\!\circ\, O_2 \wedge O_2 \,|\!\circ\, O_1 \wedge \textit{Force}\text{-}\textsc{Support}(O_1, O_2))$ ((b) O_1 BLOCKed by O_2)
3. $\text{In\_Contact}(O_1, O_2) = (O_1 \,|\!\circ\, O_2 \wedge O_2 \,|\!\circ\, O_1 \wedge EC(O_2, O_1))$ ((c) O_1 in CONTACT with O_2)

$$\text{On\_Path\_Toward}(O_1, O_2) \wedge \mathbf{F}\big(\, \text{Blocked\_By}(O_1, O_2) \wedge \mathbf{G}(\text{In\_Contact}(O_1, O_2))\,\big)$$

Naturally, the relationship in which one object comes to a halt and remains in CONTACT with the blocking object is only one of many scenarios that can take place. In the paper we look at different cases of CAUSED_MOVEMENT and illustrated below is the event of 'bouncing'.



3. $\text{Bouncing}(O_1, O_2) = O_1 \hookleftarrow O_2 \wedge O_2 \,|\!\circ\, O_1 \wedge DC(O_1, O_2)$
((c) O_1 on PATH from O_2 which is at rest in respect of O_1)

$$\text{On\_Path\_Toward}(O_1, O_2) \wedge \mathbf{F}\big(\, \text{Blocked\_By}(O_1, O_2) \wedge \mathbf{F}(\textit{Bouncing}(O_1, O_2))\,\big)$$

A Final Word

The impact formalised image schemas could have for the advancement of artificial intelligence, commonsense reasoning and computational concept invention requires further investigations. ISL^M provides the first step towards a method on how to represent image schemas, a phenomenon from embodied cognition, while remaining in the classic knowledge representation area, making it compatible with a range of existing methods and systems.

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