Image Schemas as Families of Theories

Maria M. Hedblom[1], Oliver Kutz[2], and Fabian Neuhaus[1]

[1] Department for Knowledge and Language Engineering (IWS)
Otto-von-Guericke University of Magdeburg, Germany
[2] Research Centre for Knowledge and Data (KRDB)
Free University of Bozen-Bolzano, Italy

Abstract. Image schemas are recognised as a fundamental ingredient in human cognition and creative thought. They have been studied extensively in areas such as cognitive linguistics. However, the very notion of image schemas is still ill-defined, with varying terminology and definitions throughout the literature. For the purpose of formalising image schemas in order to exploit their role in computational creative systems, we here study the viability of the idea to formalise image schemas as graphs of interlinked theories. We discuss in particular a selection of image schemas related to the notion of 'path' and show how they can be mapped to a formalised family of micro theories reflecting the different aspects of path following.

Keywords: concept invention, image schemas, computational creativity

1 Introduction

The cognitive processes for concept invention are still largely unexplored ground. One of the theories trying to explain concept generation follows from the embodied mind theory [1, 2], i.e. the idea that our conceptual world is derived from our bodily experiences and interactions with the environment. Following this reasoning the theory of image schemas emerged as a possible explanation for concept formation and conceptual understanding.

The theory of image schemas was jointly developed by Lakoff [3] and Johnson [4]. It proposes that human cognition is grounded in our bodily experience with our environment, and that this embodied experience is at the heart of how we structure our concepts, even the most abstract ones.

According to Johnson [4], *"an image schema is a recurring dynamic pattern of our perceptual interaction and motor programs that gives coherence and structure to our experience."*

Following this definition, image schemas offer a connection between the relationships of physical objects in time and space and the conceptual world. This indicates that a formal approach to image schemas could come to aid the development of artificial intelligence and computational concept invention.

However, the current state of image schema research makes formal approaches challenging. There is a lot of incoherence regarding the terminology concerning image schemas: the borders between different image schemas are vague and overlapping; it is also unclear where to draw the line regarding what spatial relationships should be called image-schematic (cf. image schema concepts In and Out, with directional concepts such as left and right). While the current research in cognitive linguistics [5] and developmental psychology [6] provides some first steps towards a more unified terminology, the identification of these abstract patterns has been established to be difficult.

In previous formal approaches to image schemas (e.g. [7–9]) a valuable portfolio of approaches can be found to build on further. However, more attention still needs to be paid to building a more unified terminology integrating the formal and cognitive-linguistic approaches found in the literature [10], whilst allowing a more systematic formalisation strategy.

Our principle claim in this paper is that the 'Gestalt' idea of image schemas should be analysed as family-resemblance, and furthermore that the formal analysis of this 'family-resemblance' should provide a set (i.e. a *family*) of interlinked theories (in the weakest case, a set of theories ordered by logical entailment, giving rise to a lattice), each of which covering a particular conceptual-cognitive scenario within the schema.

To illustrate our approach, we will use the image-schematic structure found in language to suggest how image schemas can be represented as lattices of theories. This illustrates how simple image schemas can be made more elaborate within their respective 'family'.

To further illustrate our formal approach, we will use the image schema of Path-following, analyse its connections to natural language, and sketch-out a lattice axiomatised in first-order logic, which makes explicit the different branching points of micro theories involved in the family.

The remainder of the paper is structured as follows: first, image schemas are introduced, including explaining the image schema of Path-following. This is followed by a section on the usage of image schemas in language to support the hypothesis that image schemas can be formally organised in interconnected families. The next sections deal with formal approaches to image schemas by sketching out a particular lattice by providing a first-order logic axiomatisation of Path following. Finally, we discuss the relationship to other formal, logic-based approaches, and give an outlook to future work including empirical studies to give further evidence for the fruitfulness of our approach and the proposed formal distinctions within image schema families.

2 Image schemas

Image schemas are suggested to be the conceptual building blocks that are formed in early infancy as a result of bodily experiences with the environment [11]. They are found independently of language and culture [12] and are thought to form and begin to play a conceptual role as an infant comes into contact with particular spatial relationships through sensory-motor processes. The involved relationships are learnt and can be generalised upon. Such mental patterns of spatial relationships are what constitutes image schemas. Some of the most commonly mentioned image schemas are: CONTAINMENT, PATH, SUPPORT and LINK.

Image schemas can be used to explain increasingly more involved concepts when combined with each other. E.g., Kuhn suggests that 'transportation' can be understood as a combination of the image schemas SUPPORT and PATH [7] and 'Marriage' can be describes as a LINKED_PATH [6].

Image schemas constitute the mental representation of expectations in different situations. Their cognitive benefit lies therefore in their generalised nature, which enables analogical transfer of knowledge or expectations onto unknown situations. E.g., if the image schema of SUPPORT has been learnt through exposure of plates on tables, an infant can infer that desks can SUPPORT books as well. The image schema becomes increasingly fine-tuned as the infant is repeatedly exposed to the same relationship in different situations [13]. This results in an image schema family capturing the same relationship yet with different levels of specification.

One of the more famous examples of grounding abstract concepts in image schemas is the work of Lakoff and Nünez [14]. In *Where Mathematics Comes From*, they explained how image schemas may lay the foundation for abstract concepts in mathematics, beginning with examples of how the notions of addition and subtraction can be derived from back and forward movements along a PATH, and leading to more abstract constructions such as complex numbers.

Due to the basic nature of image schemas these mental patterns may be combined with each other to generate more complex structures [7, 8, 11, 15]. E.g., the notion of PATH can easily be connected with LINK resulting in a higher level image schema such as LINKED_PATH: An image schema concept that encompasses linked behaviour on two, or more, joint PATHs. This "Gestalt" grouping of image schemas means that there must be a distinction between the most perceptually primitive image schemas and the more complex image schemas.

Building on empirical data from studies on cognitive development, one hierarchical approach to solve this is the distinction made by Mandler and Cánovas [11]. They divide the umbrella term 'image schemas' into three different levels: *spatial primitives* (the conceptual building blocks), *image schemas*[3] (simple spatial stories), and *conceptual integrations* (image schemas combined with a non-spatial element such as force or emotion).[4]

The image schema PATH is a family of image schemas that ranges from the spatial primitive of basic movement, to more complex image schema notions such as SOURCE_PATH and PATH_GOAL. Higher levels include CYCLE in which the start and end in the SOURCE_PATH_GOAL schema are identical. Overlapping image schemas, that are combinations of the PATH family and other im-

[3] If referring to this level we will use the term *spatial schemas* to avoid confusion.

[4] For the purposes of this paper, only spatial primitives and spatial schemas will be further discussed. In principle, our approach is general enough to allow for heterogeneity, also on the logical level. Therefore we may also include conceptual integrations involving non-spatial elements in our image schema families, cf. the discussion in sections 4 and 5.

age schema families are for example: BLOCKAGE, REVOLVING_MOVEMENT and LINKED_PATH.

Below, we provide a more thorough description of the PATH family.

The Case of Path Following. Mandler [6, p.78] defined the image schema PATH as "[...] the simplest conceptualization of any object following any trajectory through space, without regard to the characteristics of the object or the details of the trajectory itself – it is merely something moving in through space."

Given that the most general notion of PATH simply is movement, it follows that PATH is one of the first image schemas to be acquired in early infancy as children are immediately exposed to movement from a range of objects. This in combination with the neurological priority to process moving objects over static objects, the image schema is suggested to be either innate [16] or learnt at a very early stage in cognitive development.

During the initial stages of cognitive development, children pay more attention to the actual movement on the PATH rather than the cause and/or target of the movement. However, as the child becomes more and more familiar with the image schema, more details are added. This means that in more advanced stages, the image schema encompasses beyond movement and the spatial PATH itself, also the spatial primitive END_PATH, and later also a START_PATH[5]. Studies on infants [11] indicate that already at five months infants can distinguish PATH_GOAL from the initial PATH, while the START_PATH is less interesting until the end of the first year of life. This is further supported by linguistic analyses in which an END_PATH is initially more interesting than a START_PATH [17].

During the first year of an infant's life it learns to distinguish between several different components, or spatial primitives, that are all connected to the same image schema. In Sec. 4, we will demonstrate this fine-tuning via a collection of formal theories. In language, these patterns can be similarly observed, strengthening the hypothesis that image schemas are not isolated notions, but should be seen as interconnected families of theories or concepts. The next section aims to demonstrate this phenomenon.

3 Use of Image Schemas in Natural Language

In this section, we examine the use of the PATH image schema in language. One question is how to identify the use of an image schema.

Bennett and Cialone [18] investigated the CONTAINMENT relationship in natural language by analysing text corpora. The CONTAINMENT image schema is commonly described as the sum of the interrelationships of an inside, an outside and a boundary [3]. Bennett and Cialone searched for words similar to containment, e.g. 'surrounding' and 'enclosing'. Further, the preposition "in" is used to

[5] In this paper we follow the terminology of [11]. Alternative terms for START_PATH and END_PATH are 'Source' and 'Goal', respectively. These are used in the names of image schemas like SOURCE_PATH, PATH_GOAL, and SOURCE_PATH_GOAL.

describe a CONTAINMENT relationship. Prepositions in combination with verbs often do appear to be the key words that help identify image schemas in language [17].

One abstract example of CONTAINMENT is *"to be in love"*. Obviously, there are no spatial regions for the state of love in the same sense as there are for a physical container like a milk bottle. Yet, we use the spatial language to talk about the phenomenon of love: e.g., we fall in love or fall out of love. Bennett and Cialone's method distinguished at least eight different kinds of CONTAINMENT.

Their approach illustrates that analysing language leads to greater understanding of image schemas. In the rest of this section we discuss examples for different uses of PATH image schemas.

The Uses of Path-Following. As demonstrated above with CONTAINMENT, in metaphorical language, image schemas can be used as a source for grounding abstract concepts in already comprehended concrete concepts. For the image schema of PATH-following there is a multitude of metaphoric expressions that work on different levels of specification in a hierarchy, or as we call it the PATH family.

The most basic examples of PATH following in natural language are situations that immediately speak of the spatial relationship of movement between different points. Prepositions such as *from, to, onto, into, across* and *through*, all indicate movement and the image schema PATH. This also includes key verbs that are connected to movement, e.g. *going, coming.*

Concrete examples of PATH in natural language include *I am on a train from Berlin to Prague* (SOURCE_PATH_GOAL), and more abstract concepts *Going on a joy ride* (SOURCE_PATH, as there often is no intended goal).

The metaphorical expression *"to run for president"* does not mean, in most cases, that a person is running a marathon for their head of state. It illustrates the process of trying to get elected as president: PATH_GOAL.

Another metaphor *"life is a journey"* [19] makes an analogical mapping between the passing of time in life, to the passing of spatial regions on a journey. As in the example above, where the concept of "being in love" acquired information from the CONTAINMENT schema, the metaphor gains information from the spatial primitives connected to this image schema. For PATH, the most basic spatial primitives are START_PATH and END_PATH – in this metaphor they are mapped to the moments of birth and death.

A different perspective on life and death is expressed in the metaphorical expression *"the circle of life"*. Implied is that life leads to death, but death also gives rise to life, completing a cyclic movement—the image schema CYCLE. This image schema can be considered as a version of PATH following, in which START_PATH and END_PATH coincide at the same 'location'.

These examples illustrate a general pattern, namely that many metaphors involving PATHs are about processes, and different events during the process are treated metaphorically as locations on the path. This leads to the conceptualisation of the abstract concept of time, which we will further investigate in the next section.

Time as Path. Time is often represented as a linear PATH, which moves forward in one direction. In particular, if we want to represent the change of some property over time (e.g., the population of a city, the acceleration of a falling object, the GDP of a country) we often use a two-dimensional coordinate system where the vertical axis represents the property in question and the horizontal axis represents time.

Perceived like a PATH, time can be observed with several of the spatial primitives associated with the image schema. Time may be conceptualised as having a beginning, a START_PATH; e.g., this may be the Big Bang or the moment of creation in a religious context. Depending on the cosmological preferences, time may also be conceptualised to have an end, an END_PATH: the Big Rip or an 'apocalypse'.

In other contexts, time is not represented as a linear PATH but as iterative CYCLE. After each winter follows another spring, every sunset is followed by another sunrise, and the arms of a clock move round and round. Thus, time can be seen as a cyclic process, as each day, week and year starts anew.

The past section has outlined the motivation for why the image schema of PATH-following should be seen as more than movement in any trajectory. Different PATH notions can be identified by distinguishing their specific use in natural language. Next follows our suggestion on how these notions can be structured in accordance with Mandler and Cánovas' [11] distinctions of spatial primitives.

4 Image Schema Families as Graphs of Theories

In the previous sections, we argued for image schemas to be members of families, which are partially ordered by generality. In the following, we will describe an approach to represent the connections between image schemas, belonging to the same family according to certain criteria. To illustrate some technical points, we will sometimes also postulate the existence of additional image schemas and their interconnections[6], whilst others are clearly motivated and instantiated by examples from the previous section. Formally, we can represent this idea as a graph[7] of theories in DOL, the *Distributed Ontology, Modeling and Specification Language* [20].

This choice is motivated primarily by two general features of DOL: (1) the heterogeneous approach which allows for a variety of image schematic formalisations without being limited to a single logic, and (2) the focus on linking and modularity. Therefore, DOL provides a rich toolkit to further formally develop the idea of *image schema families* in a variety of directions.[8]

[6] A disclaimer: in such cases we here do not intend to make any claims regarding their empirical existence and/or their cognitive role in development.

[7] These graphs are diagrams in the sense of category theory.

[8] In more detail, DOL aims at providing a unified metalanguage for handling the diversity of ontology and specification languages, and in particular provides constructs for (i) "as-is" use of ontologies, models and specifications (OMS) formulated (as a logical theory) in a specific ontology, modelling or specification language, (ii) OMS

Building on similar ideas to those underlying the first-order ontology repository COLORE[9] [21], we propose to capture image schemas as interrelated families of (heterogeneous) theories. Similar ideas for structuring common sense notions have also been applied to various notions of time [22, 23]. This general approach also covers the introduction of non-spatial elements such as 'force' as a basic ingredient of image schemas, as for instance argued for in [24].

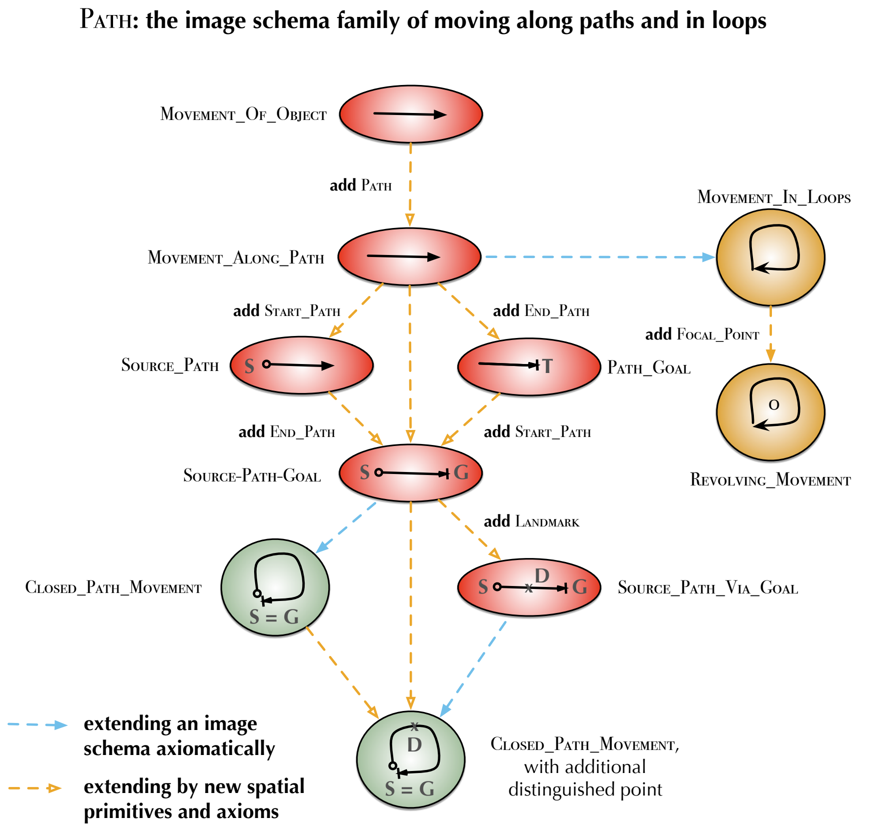

Fig. 1. A portion of the family of image schemas related to path following shown as DOL graph.

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formalised in heterogeneous logics, (iii) modular OMS, (iv) mappings between OMS, (v) networks of OMS, and (vi) queries. DOL is equipped with an abstract model-theoretic semantics. The final DOL specification was submitted as a standard to the Object Management Group (OMG) in early 2015

[9] See `http://stl.mie.utoronto.ca/colore/`

In Figure 1, some of the first basic stages of the image schema family PATH are presented. Ranging from Mandler's general definition presented above, of object movement in any trajectory, to more complex constructions.

The particular image schema family sketched is organised primarily via adding new spatial primitives to the participating image schemas and/or by refining an image schema's properties (extending the axiomatisation). In general, different sets of criteria may be used depending, for example, on the context of usage, thereby putting particular image schemas (say, REVOLVE_AROUND) into a variety of families. Apart from a selection of spatial primitives, other dimensions might be deemed relevant for defining a particular family, such as their role in the developmental process.

One way MOVEMENT_ALONG_PATH can be specialised is as the image schema of MOVEMENT_IN_LOOPS. Note that this change does not involve adding a new spatial primitive, but just an additional characteristic of the path. The resulting image schema can be further refined by adding the notion of a *focal point*, which the path revolves around—this leads to the notion of orbiting. Alternatively, we may change MOVEMENT_ALONG_PATH by adding distinguished points; e.g., the START_PATH, the target END_PATH, or both.

The latter image schema may be further specialised by identifying (the location of) the START_PATH and the END_PATH. In this case, the path is closed in the sense that any object which follows the path will end up at the location at where it started its movement. The difference between a closed path and a looping path is that the closed path has a start and an end (e.g., a race on a circular track), while the looping path has neither (like an orbit). It is possible to further refine the schema by adding more designated points or other related spatial primitives.

We will now show how the theories of image schemas and the various branching points in the graph can be characterised formally.

5 Axiomatisation of Path-Following

In this section, we present an axiomatisation of the image schema represented in Figure 1. The focus of our axiomatisations is to capture the important differences of the branching points of the PATH family, not an exhaustive axiomatisation. For the sake of brevity, we will present only selected axioms in this section. A more complete axiomatisation is available at an Ontohub repository.[10]

Our axiomatisation approach is inspired by semantics in the neo-Davidsonian tradition [25, 26]. We consider image schemas as a type of event (in generality quite similar to the view defended in [27] to view image schemas as a kind of 'domain') and consider spatial primitives as thematic roles of these events. Thus, if a given image schema is enriched by adding a new spatial primitive, this is typically represented by adding a new entity (e.g., site) and a new relation (e.g., has_start_path) that determines the thematic role of the new entity in the event.

[10] `https://ontohub.org/repositories/imageschemafamily/`

As representation language we use ISO/IEC 24707 Common Logic. Common Logic is a standardised language for first-order knowledge representation, which supports some limited form of higher-order quantification and sequence variables.

For the axiomatisation of the image schemas in the family of path following we assume an image schema MOVEMENT_ALONG_PATH as the root of the PATH family. MOVEMENT_ALONG_PATH is derived from a more general notion, namely MOVEMENT_OF_OBJECT. This is movement of some kind that involves only one spatial primitive, namely an OBJECT. This object plays the role of the *movee* within the context of the MOVEMENT. This can be formalised in first-order logic as follows:

```
(forall (m)
  (iff
    (MovementOfObject m)
    (exists (o)
      (and
        (Movement m)
        (Object o)
        (has_movee m o)))))
```

No additional information about what kind of object is moving and how it is moving is assumed.[11]

The schema MOVEMENT_ALONG_PATH is the result of adding a new spatial primitive to MOVEMENT_OF_OBJECT, which plays the role of a PATH.

```
(forall (m)
  (iff
    (MovementAlongPath m)
    (exists (p)
      (and
          (MovementOfObject m)
          (Path p)
          (has_path m p)))))
```

Under a PATH we understand a collection of two or more sites, which are connected by successor relationships. Each of these sites has (relative to the path) at most one successor site. The transitive closure of the successor relation defines a *before* relationship (relative to the path); and for any two different sites x, y of a given path, either x is before y or y is before x (relative to the path).[12]

This axiomatisation provides a representation of a quite abstract notion of MOVEMENT_ALONG_PATH. It needs to be sufficiently abstract, since it serves as the root node for the PATH family. All other image schemas in the family are derived from this root by adding additional spatial primitives and/or additional axioms.

[11] From an ontological perspective, MOVEMENT_OF_OBJECT can be seen as a kind of process (or occurrent). Thus, any adequate axiomatisation of MOVEMENT_OF_OBJECT needs to represent change over time in some form. To keep things simple, we here just quantify over time points. We assume that time points are ordered by an `earlier` relationship. Further, we use two other relationships to connect time points to processes: `(has_start m t)` means *The movement m starts at time point t* and `(during t m)` means *Time point t lies within the interval during which movement m happens.*

[12] The before-relationship is not a total order, since antisymmetry is not postulated.

Given this notion of PATH, we can axiomatise the relationship between the PATH and the OBJECT, which characterises a MOVEMENT_ALONG_PATH. During the movement the moving object needs to pass through all sites of the path in a temporal order, which matches the before-relationship between the sites:

```
(forall (p o m s1 s2)
  (if
    (and
      (MovementAlongPath m)
      (has_path m p)
      (has_movee m o)
      (before s1 s2 p))
    (exists (t1 t2)
      (and
        (Timepoint t1) (Timepoint t2)
        (during t1 m)  (during t2 m)
        (located_at o s1 t1) (located_at o s2 t2)
        (earlier t1 t2)))))
```

The image schema SOURCE_PATH is the result of adding the spatial primitive START_PATH to MOVEMENT_ALONG_PATH. We represent this with the *has_source* relationship. The START_PATH of a PATH is a site on the path that is before any other site of the path:

```
(forall (m)
  (iff
    (SourcePathMovement m)
    (exists (s)
      (and
          (MovementAlongPath m)
          (has_start_path m s)))))
```

```
(forall (m s1 s2 p)
  (if
    (and
      (SourcePathMovement m)
      (Site s1)
      (Site s2)
      (not (= s1 s2))
      (has_path m p)
      (has_start_path m s1)
      (part_of s2 p))
    (before s1 s2 p)))
```

What distinguishes SOURCE_PATH from other movements is the following: at the start of a SOURCE_PATH movement the object that moves is located at the START_PATH:

```
(forall (m s t p o)
  (if
    (and
      (SourcePathMovement m)
      (has_start m t)
      (has_movee m o)
      (has_start_path m s))
    (located_at o s t))))
```

Analogously, we can define PATH_GOAL as a MOVEMENT_ALONG_PATH with an END_PATH. A SOURCE_PATH_GOAL is a movement, which includes both landmarks of START_PATH and END_PATH. Thus, SOURCE_PATH_GOAL can be defined as the intersection of SOURCE_PATH and PATH_GOAL.

CLOSED_PATH_MOVEMENT is a special case of SOURCE_PATH_GOAL, where the location of the START_PATH and the END_PATH of the PATH coincide.

```
(forall (m s g)
  (if
    (and
        (has_start_path m s)
        (has_end_path m g))
    (iff
```

```
      (ClosedPathMovement m)
      (and
        (SourcePathGoalMovement m)
        (= (location_of s) (location_of g))))))
```

SOURCE_PATH_VIA_GOAL is a different way to refine SOURCE_PATH_GOAL. In this case an additional designated site is added, which lies between the START_PATH and the END_PATH of the path.

```
(forall (m)
  (iff
    (SourcePathViaGoalMovement m)
    (exists (s p)
      (and
        (SourcePathGoalMovement m)
        (has_path m p)
        (Site s)
        (part_of s p)
        (not (has_start_path m s))
        (not (has_end_path m s))))))
```

Both CLOSED_PATH_MOVEMENT and SOURCE_PATH_VIA_GOAL can be combined in the obvious way.

A completely different branch of the movement image schema family does not involve either START_PATH or END_PATH, but the PATH consists of a loop of sites. One way to represent this is by requiring that the before-relationship is reflexive (with respect to the path of the movement):

```
(forall (m)
  (iff
    (MovementInLoops m)
    (and
      (MovementAlongPath m)
      (forall (p s)
        (if
          (and
            (has_path m p)
            (Site s)
            (part_of s p))
          (before s s p))))))
```

The difference between MOVEMENT_IN_LOOPS and CLOSED_PATH_MOVEMENT is that in the latter case both START_PATH and END_PATH are present, they just spatially coincide. Hence, the movement is over when the object meets the target. In contrast, MOVEMENT_IN_LOOPS entails that the moving object is located at the same location more than once.

REVOLVING_MOVEMENT is a subtype of MOVEMENT_IN_LOOPS. To define it, we need to consider two additional factors: the shape of the path is elliptical, and there is a focal point, which the movement revolves around. The focal point itself is a site, but it is typically the location of an object. A detailed axiomatisation of this image schema is beyond the scope of this paper, we just provide an initial sketch:

```
(forall (m)
  (iff
    (RevolvingMovement m)
    (and
      (MovementInLoops m)
      (exists (p s)
        (and
```

```
(has_path m p)
(Eliptical (shape p))
(Site s)
(has_focal_point p s))))))
```

6 Discussion and related work

Formalising image schemas is a recent undertaking in artificial intelligence research as a means to aid computational concept invention [28, 8, 29–31].

We have here presented an approach in which image schemas are treated as interconnected theories in a lattice (ordered by theory interpretation). We have discussed the usage of image schema structure in language and the cognitive development of spatial primitives and image schemas. The main insights, we claim, support the hypotheses that the spatial primitives and their assumed properties distinguish not only the different usages in natural language and various cognitive stages, but can be systematically seen as and mapped to branching points in the lattice of image schema theories.

The benefits of this approach lie not only in the provided structuring of image schemas, but also in how formal systems may use them. In analogy engines, or (formal) approaches to conceptual blending [32, 31],the presented hierarchy can provide a method for theory weakening based on abstracting involved image schemas, and is therefore substantially different from the more syntactic-driven methods used by the Structure Mapping Engine (SME) [33] or Heuristic-Driven Theory Projection (HDTP) [34].

A similar approach to that presented here can be found in St. Amant et al. [9]. In what they call Image Schema Language, ISL, they provide a set of diagrams that illustrate how combinations of image schemas can lead to more complex image schemas, and provide some real life examples.

Other related work on formalising image schemas is the work of Kuhn [28, 35]. He argues that image schemas capture abstractions in order to model affordances. Working top-down rather then our bottom-up approach, he uses WordNet to define noun words and connects them to spatial categorisations related to image schemas based on affordance-related aspects of meaning.

Walton and Worboys [8] build further on Kuhn's work by visualising and formalising the connections between different image schemas using bigraphs. By visually representing the topological and 'physical' image schemas relevant in built environments, they demonstrate how more complex dynamic image schemas such as BLOCKAGE could be generated using sequences of bigraph reaction rules on top of simpler static image schemas.

Our work differs from the approaches above by focusing on making explicit the structure of entire image schema families, using PATH as a proof of concept. While other approaches tend to look at the interconnection between particular image schemas, we have followed the psychological research of Mandler and Cánovas [11] to analyse formally the image schema family of PATH concentrating on the involved spatial primitives. It is our belief that this will allow for a more fine-tuned and specialised use of image schemas in computational systems.

Complex image schemas partly develop as a result of combining elements from different image schemas. This paper has not studied the interconnections between this family and other image schema families in detail. For a more extensive structuring of image schemas and their families, the combination of different image schema families needs to be addressed.

This leads to two major issues that need to be addressed in our approach. Namely first: that while we argue that image schemas can be structured in families, there is bound to be overlapping nodes that are also part of other image schema families, indicating the need for integration with approaches like that from St. Amant et al. introduced above. Here, the DOL language provides some of the tools to make such an interconnection of families formally feasible, and to give a handle on a formal rendering of the notion of *construal* (image schema transformation) discussed in [27].

The second problem is the temporal nature of image schemas. Since image schemas are not only spatial but also capture change over time, any axiomatisation thereof needs to address the non-trivial problem of formally representing time. One motivation for the use of non-classical logics is the claim that these are cognitively and linguistically more adequate than classical logics involving variables and direct quantification over objects [36]. Moreover, the cognitive adequateness of particular formalisms has been studied in detail (e.g. [37]). In this spirit, a large variety of temporal logics has been proposed to model various temporal aspects of natural language [38, 22]. Similarly, qualitative spatial logics have been designed to capture more adequately the way humans conceptualise and reason about space [39].

In this line of thinking, a challenging research program would involve not to uniformly represent different kinds of image schemas in one expressive logic, such as first- or higher-order logic, but instead to construct a mapping between the cognitive levels of image schema development and correspondingly adequate logical representations on different layers of abstraction. For instance, the gradual construction of an explicit representation of a time-line over which humans might meaningfully be able to quantify, could be bootstrapped from the most basic path following image schema where a progression of time is completely implicit in the notion of movement along the path understood as a basic event.

As a next step, we intend to establish the potential of our approach by performing two kinds of empirical studies on image schema families. (1) We plan to evaluate the hypothesis that the basic image schemas within a family can be found in any language and are, thus, universal. (2) We intend to investigate the branching points within image schemas, that are realised differently in a variety of languages and where, thus, universality of the image schemas breaks down.

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References

1. Barsalou, L.W.: Grounded cognition. Annual review of psychology **59** (2008) 617–645
2. Gallese, V., Lakoff, G.: The brain's concepts: the role of the sensory-motor system in conceptual knowledge. Cognitive neuropsychology **22**(3) (5 2005) 455–79
3. Lakoff, G.: Women, Fire, and Dangerous Things. What Categories Reveal about the Mind. The University of Chicago Press (1987)
4. Johnson, M.: The Body in the Mind. The Bodily Basis of Meaning, Imagination, and Reasoning. The University of Chicago Press (1987)
5. Hampe, B., Grady, J.E.: From perception to meaning: Image schemas in cognitive linguistics. Volume 29 of Cognitive Linguistics Research. Walter de Gruyter (2005)
6. Mandler, J.M.: The Foundations of Mind : Origins of Conceptual Thought: Origins of Conceptual Though. Oxford University Press, New York (2004)
7. Kuhn, W.: An image-schematic account of spatial categories. (2007) 152–168
8. Walton, L., Worboys, M.: An algebraic approach to image schemas for geographic space. In: Proceedings of the 9th International Conference on Spatial Information Theory (COSIT), France (2009) 357–370
9. St. Amant, R., Morrison, C.T., Chang, Y.H., Cohen, P.R., Beal, C.: An image schema language. In: International Conference on Cognitive Modeling (ICCM). (2006) 292–297
10. Hampe, B.: Image schemas in cognitive linguistics: Introduction. In Hampe, B., Grady, J.E., eds.: From perception to meaning: Image schemas in cognitive linguistics. Walter de Gruyter (2005) 1–14
11. Mandler, J.M., Pagán Cánovas, C.: On defining image schemas. Language and Cognition **0** (5 2014) 1–23
12. McDonough, L., Choi, S., Mandler, J.M.: Understanding spatial relations: Flexible infants, lexical adults. Cognitive Psychology **46**(3) (5 2003) 229–259
13. Mandler, J.M.: On the birth and growth of concepts. Philosophical Psychology **21**(2) (4 2008) 207–230
14. Lakoff, G., Núñez, R.E.: Where Mathematics Comes From. Basic Books (2000)
15. Oakley, T.: Image schema. In Geeraerts, D., Cuyckens, H., eds.: The Oxford Handbook of Cognitive Linguistics. Oxford University Press (2007) 214–235
16. Rohrer, T.: Image schemata in the brain. In Hampe, B., Grady, J.E., eds.: From perception to meaning: Image schemas in cognitive linguistics. Volume 29 of Cognitive Linguistics Research. Walter de Gruyter (2005) 165–196
17. Johanson, M., Papafragou, A.: What does children's spatial language reveal about spatial concepts? evidence from the use of containment expressions. Cognitive science **38**(5) (6 2014) 881–910
18. Bennett, B., Cialone, C.: Corpus guided sense cluster analysis : a methodology for ontology development (with examples from the spatial domain). (2014) 213–226
19. Ahrens, K., Say, A.L.: Mapping image schemas and traslating metaphors. In: Proceedings of Pacific Asia Conference on Language, Information and Computation. (February 1999) 1–8
20. Mossakowski, T., Codescu, M., Neuhaus, F., Kutz, O.: The distributed ontology, modelling and specification language - DOL. Studies in Universal Logic. In: The Road to Universal Logic–Festschrift for 50th birthday of Jean-Yves Beziau, Volume II. Birkhäuser (2015)
21. Grüninger, M., Hahmann, T., Hashemi, A., Ong, D., Ozgovde, A.: Modular First-Order Ontologies Via Repositories. Applied Ontology **7**(2) (2012) 169–209

22. Van Benthem, J.F.A.K.: The Logic of Time. D. Reidel Publishing Company, Dordrecht, Holland (1983)
23. Allen, J., Hayes, P.: A common-sense theory of time. In: Proceedings of the 9th International Joint Conference on Artificial Intelligence (IJCAI-85), Los Angeles, CA, USA (1985) 528–531
24. Gärdenfors, P.: Cognitive semantics and image schemas with embodied forces. In: Embodiment in Cognition and Culture. Volume 71 of Advances in Consciousness Research. John Benjamins Publishing Company (2007) 57–76
25. Davidson, D.: The logical form of action sentences. In Rescher, N., ed.: The logic of decision and action, Pittsburgh (1967) 81–94
26. Parson, T.: Events in the Semantics of English: A Study in Subatomic Semantics. MIT Press (1990)
27. Clausner, T.C., Croft, W.: Domains and image schemas. Cognitive Linguistics **10**(1) (1999) 1–31
28. Kuhn, W.: Modeling the Semantics of Geographic Categories through Conceptual Integration. In: Proc. of GIScience 2002, Springer (2002) 108–118
29. Morgenstern, L.: Mid-Sized Axiomatizations of Commonsense Problems: A Case Study in Egg Cracking. Studia Logica **67** (2001) 333–384
30. Goguen, J.A., Harrell, D.F.: Style: A Computational and Conceptual Blending-Based Approach. In Argamon, S., Dubnov, S., eds.: The Structure of Style: Algorithmic Approaches to Understanding Manner and Meaning. Springer, Berlin (2010) 147–170
31. Kutz, O., Bateman, J., Neuhaus, F., Mossakowski, T., Bhatt, M.: E pluribus unum: Formalisation, Use-Cases, and Computational Support for Conceptual Blending. In Besold, T.R., Schorlemmer, M., Smaill, A., eds.: Computational Creativity Research: Towards Creative Machines. Thinking Machines. Atlantis/Springer (2014)
32. Turner, M.: The Origin of Ideas: Blending, Creativity, and the Human Spark. Oxford University Press (2014)
33. Gentner, D.: Structure mapping: A theoretical framework for analogy. Cognitive Science **7**(2) (1983) 155–170
34. Schmidt, M., Krumnack, U., Gust, H., Kühnberger, K.u.: Computational Approaches to Analogical Reasoning: Current Trends. Volume 548 of Studies in Computational Intelligence. Springer Berlin Heidelberg (2014)
35. Kuhn, W.: An Image-Schematic Account of Spatial Categories. In Winter, S., Duckham, M., Kulik, L., Kuipers, B., eds.: Spatial Information Theory. Volume 4736 of Lecture Notes in Computer Science. Springer (2007) 152–168
36. Blackburn, P., de Rijke, M., Venema, Y.: Modal Logic. Cambridge Tracts in Theoretical Computer Science. Cambridge University Press (2001)
37. Knauff, M., Rauh, R., Renz, J.: A cognitive assessment of topological spatial relations: Results from an empirical investigation. In Hirtle, S.C., Frank, A.U., eds.: Spatial Information Theory: A Theoretical Basis for GIS. Volume 1329 of Lecture Notes in Computer Science. Springer (1997) 193–206
38. Prior, A.N.: Past, Present and Future. Oxford University Press, Oxford (1967)
39. Cohn, A.G., Renz, J.: Qualitative spatial representation and reasoning. In van Harmelen et al., F., ed.: Handbook of Knowledge Representation. Elsevier, Oxford (2007) 551–596