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Image Schemas and Concept Invention: Cognitive, Logical, and Linguistic Investigations

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OKAY, WELL, SOMETIMES SCIENCE IS MORE ART THAN SCIENCE, MORTY.

A LOT OF PEOPLE DON'T GET THAT.

- RICK SANCHEZ

MARIA M. HEDBLOM

IMAGE SCHEMAS AND CONCEPT INVENTION

COGNITIVE, LOGICAL, AND LINGUISTIC INVESTIGATIONS

THESIS SUBMITTED FOR THE DEGREE OF **DOCTOR OF ENGINEERING**
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Magdeburg, January 2019
Maria M. Hedblom

Thank You

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Sincerely yours
Maria

Zusammenfassung

Deutsch

Image Schemas wurden in der kognitiven Linguistik als mentale Verallgemeinerungen verkörperter Erfahrungen (embodied experiences) eingeführt, die Begriffe erfassen wie CONTAINMENT, SUPPORT und SOURCE_PATH_GOAL-Bewegung. Diese raumzeitlichen Beziehungen finden sich in der menschlichen Kognition als Informationsskelette für analogisches Denken wieder, als eine fundierende Basis für abstrakte Sprache, sowie als Bausteine für die Strukturierung von Konzepten und Ereignissen.

Trotz der Fortschritte die sich in der KI-Forschung beobachten lassen, haben Computer-basierte Systeme nach wie vor Schwierigkeiten, natürliche Sprache semantisch zu erfassen, sinnvoll per Analogie zu schließen, und kreative Fähigkeiten, zum Beispiel bzgl. der Erfindung neuer Konzepte, zu zeigen. Da Image Schemas für diese Fähigkeiten in der menschlichen Kognition eine zentrale Rolle zu spielen scheinen, ist die zentrale Hypothese dieser Dissertation, daß eine Integration formalisierter Image Schemas die komputationalen Ansätze in den entsprechenden Bereichen bereichern und verbessern wird. Die vorliegende Dissertation präsentiert die notwendigen Vorarbeiten, um die Fruchtbarkeit dieser Hypothese zu untersuchen. Diese umfassen einen theoretischen Rahmen für die Formalisierung von Image Schemas und deren Integration in Ansätze zur komputationalen Konzepterfindung.

Der Beitrag des theoretischen Rahmenwerks umfasst drei Aspekte. Erstens, aufbauend auf linguistischer und psychologischer Forschung, wird vorgeschlagen, Image Schemas in vernetzte Familiengruppen zu organisieren, in welchen Komplexitaet anwächst durch das Hinzufügen von räumlichen und konzeptuellen Elementen. Zweitens wird die Image Schema Logik ISL^{FOL} eingeführt als Sprache, die Image Schemas und deren Kombination modellieren kann. Drittens werden Methoden präsentiert, die zeigen, wie die Semantik von Image Schemas genutzt werden kann, um Methoden der komputationalen Konzepterfindung zu verbessern.

Zusätzlich zum theoretischen Beitrag präsentieren wir zwei empirische Studien. Die erste Studie unterstützt die These, daß Image Schemas Konzeptualisierungen von Objekten und Konzepten modellieren. Die zweite Studie präsentiert linguistische Resultate, die die These stützen, daß Image Schemas in Familien organisiert werden, und präsentiert darüberhinaus den ersten Schritt hin zu einer Methodik, die automatisch, Image Schemas in der natürlichen Sprache identifiziert.

Abstract

English

In cognitive linguistics, image schemas were introduced as mental generalisations from embodied experiences capturing notions such as CONTAINMENT, SUPPORT and SOURCE_PATH_GOAL movement. These spatiotemporal relationships can be found in human cognition as information skeletons for analogical reasoning, as a grounding factor for abstract language and as conceptual building blocks for concepts and events.

Despite the progress seen in research on artificial intelligence, computational systems still struggle with natural language comprehension, to perform meaningful analogical transfers and to display creative capacity in terms of concept invention. The dissertation's main hypothesis is that, as image schemas appear to be a key component in these processes in human cognition, an integration of formalised image schemas could advance the computational work in these fields. This dissertation presents the prerequisites to investigate the fruitfulness of this hypothesis, namely, a theoretical framework for the formalisation of image schemas and their integration into computational conceptual blending.

The contribution of the theoretical framework is threefold. First, building on research findings from linguistics and psychology, it is argued that similar image-schematic notions should be grouped together into interconnected family hierarchies, with increasing complexity in regards to the addition of spatial and conceptual primitives. Second, the Image Schema Logic, ISL^{FOL}, is introduced as a formal language to model image schemas, as well as their combinations. Third, methods for how the semantic content of image schemas could be used to improve computational concept invention is presented.

In addition to the theoretical framework, two empirical studies are presented. The first provides support for the idea that image schemas model conceptualisations for objects and concepts. The second presents linguistic support to structure image schemas as families, as well as providing the first step towards an an automatic method to automatically identify image schemas in natural language.

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Introduction

Problem Description

In short, Mort was one of those people who are more dangerous than a bag full of rattlesnakes. *He was determined to discover the underlying logic behind the universe. Which was going to be hard, because there wasn't one.* The Creator had a lot of remarkably good ideas when he put the world together, but making it understandable hadn't been one of them.

Terry Pratchett,
Mort,1987

The symbol grounding problem is a prototypical problem in cognitive science research. From psychological, linguistic and formal perspectives, it captures the uncertainties surrounding the relationship between real-world objects and events, their mental correspondences and their symbolic representations. Due to the advancement of computer science and artificial intelligence, the symbol grounding problem is not only a philosophical problem. Instead, finding a solution has become a key component in the success of artificial intelligence.

Despite the recent progress in artificial intelligence, researchers still struggle to create systems that can be deemed to have an conceptual awareness and understanding and behave contextually appropriate, as well as by itself generate novel products and concepts. In relation to these issues, for computer science, the symbol grounding problem corresponds to the practical problem of not only how this relationship is constructed, but also how it can be modelled, formalized and eventually actualized as a means to approach these problems.

From the perspective of cognitive science, the theory of embodied cognition has been suggested as a possible solution to the symbol grounding problem. The theory proposes the hypothesis that human cognition and conceptual meaning are based on the body's sensorimotor interactions with the environment. From a psycho-philosophical point of view, the hypothesis solves some of the problems of symbol grounding as it offers a direct connection between neural activation and the meaning of words and symbols. By arguing that the meaning of a concept is a particular neural activation derived from the repeated embodied experiences associated with that concept, the theory offers a good theoretical explanation as to how symbol grounding may take place. However, also among proponents of embodied cognition, there is little consensus on how such embodied experiences mentally manifest. Consequently, there is a knowledge gap between understanding embodied experiences, their mental manifestation and their symbolic representation. The exact nature of this missing gap is for cognitive scientists to empirically explore and for computer scientists to practically try to simulate.

One theory from cognitive linguistics that aims to fill this gap is the theory of image schemas. Image schemas are thought to be the compressed generalisations of particular spatiotemporal object relations derived from repeated embodied experiences in early infancy. Classic examples include CONTAINMENT, SUPPORT and SOURCE_PATH_GOAL. These generalisations are then used as conceptual skeletons upon which meaning, analogical reasoning and causal predictions about the future can be made. They appear in how natural language often uses spatial language to describe abstract concepts, such as in 'to *enter* holy matrimony' (CONTAINMENT) or 'be *on top* of the situation' (SUPPORT and VERTICALITY). In this fashion, they take a role as a grounding factor in how symbols acquire meaning.

The problem of symbol grounding in computer science has two distinctly different characters, namely, conceptual understanding and concept invention. Both of these problems can (to some degree) be approached by using image schemas as a bridge between meaning and symbolic representation. In order to use image schemas as a method to improve on the computational issues associated with symbol grounding, the theoretical ideas behind image schemas need to be made concrete in such a way that a computational system can utilise them.

This is a non-trivial problem to solve for several reasons. First, due to the interdisciplinary research field, image schemas are subjects to terminology inconsistencies, where individual instances of image schemas are defined differently between disciplines. Second, there exists no comprehensive list of which concepts belong to the image schemas, nor does a qualification criteria exist that determine which mental constructs are image-schematic and which are not. Third, image schemas exist in both simpler, more primitive forms and increasingly complex forms where the borders between different image-schematic concepts are unclear and appear overlapping. Additionally, based on this state of image schema research from the perspective of cognitive science, formal approaches to image schemas struggle with further problems. First, the image schemas' formal structure needs attention. Second, a method to formally represent the image schemas is needed. Finally, to be proven useful for the advancement of artificial intelligence they need to be integrated into a computational framework where conceptual meaning is of the essence.

In this light, the following three research questions will be investigated further:

- First, as image schemas are abstract concepts without defined borders: *How can they be defined and organised?*
- Second, as image schemas are fluid mental patterns: *Is it possible to formally represent the individual image schemas?*
- Third, as image schemas play a role in analogical reasoning and causal predictions: *Is it possible to use image schemas to aid computational concept invention? If so, how can this be done?*

These theoretical research questions are framed, on the one hand, by empirical support and theories in cognitive linguistics, developmental psychology, theory of mind and neuroscience. On the other hand, the research also includes empirical investigations as to whether image schemas, in fact, are used as symbol grounding concepts, as well as proving a first step to an automatic method to identify image schemas in natural language. The latter is a prerequisite for the actual usefulness of image schemas in computer science.

All the major ideas are built from well-established research results and theories from the different disciplines in cognitive science. Summarised they are the following:

- The theory of embodied cognition provides a stepping stone to explain cognitive phenomena involved in concept formation.
- Image schemas are conceptual building blocks learned from embodied experience. They capture spatiotemporal relationships that in combination can capture the conceptual meaning of concepts and events.
- Conceptual blending provides a sufficiently adequate theoretical framework for concept invention that could be transferred to artificial agents.

Summary of Chapters

The first two chapters introduce the research foundation and are intended to inform the reader on issues regarding concept formation and to introduce image schema research from the direction of psychology and linguistics. The following chapters, 3-6, present theoretical work on image schemas with the intention to answer the research questions presented above. The last chapters 7 and 8 present empirical work. Chapter 7 presents an experiment that investigates the role of image schemas as building blocks for concepts, providing empirical support for the ideas presented in chapters 5 and 6. The latter presents the first step towards a method to automatically extract and identify image schemas from natural language. Simultaneously, the chapter strengthens the theoretical research results in Chapter 3 by providing empirical support from natural language.

Below each chapter is described in more detail.

Chapter 1: Creating Concepts: Considerations from Psychology and Artificial Intelligence

This chapter introduces the research foundation on which the consecutive chapters are build. After setting the scene by briefly speculating on how life can be constructed, the chapter continues to introduce the problem of symbol grounding. The problem highlights the question of how symbols such as those expressed in language, gain their meaning. This is followed by introducing the theory of embodied cognition. The theory provides a potential theoretical solution to symbol grounding by stating that all human cognition arises from the body's sensorimotor experiences. After this, a few relevant knowledge representation methods are introduced. Attention is particularly devoted to the notion of ontological knowledge structures and some problems dealing with formal ontologies. This is important as it lays the scene for the research in Chapter 3. The chapter ends with a brief introduction to creativity research with special focus on the subcategory of concept invention. Thereby, the chapter ends by returning to symbol grounding in the role it plays in concept generation. Here, information skeletons, such as those found in analogies, are discussed deeper in how they can be used in the creative generation of concepts. Additionally, the theory of conceptual blending, a theoretical framework capturing the mechanisms behind creativity and concept invention, is introduced as it plays a vital role in Chapter 6.

Chapter 2: Image Schemas: Spatiotemporal Relationships Used as Conceptual Building Blocks

Chapter 2 deals with the backbone of the conducted research, namely the theory of image schemas. In the previous chapter, embodied cognition is suggested to be a theoretical framework for how symbol grounding can be approached. This chapter explains how image schemas could be argued to function, within that framework, as the missing link between embodied experiences and mental conceptualisations. The reader is introduced to the history of image schema research, including some previous research on image schemas in cognitive linguistics and developmental psychology. From this cognitive perspective, the major issues with image schema research are highlighted in order for them to be approached both cognitively and formally in the remainder of the chapters. The first problem concerns how an interdisciplinary field such as image schema research ends up with terminology disagreements and the need for this to be resolved. The second problem concerns how to formally approach image schemas as they appear to be both internally complex, meaning that it is difficult to determine which image-schematic concepts should be called image schemas, and externally complex, meaning that borders for where one image schema ends and another begins are undefined. The second problem is further divided into what here is defined as *the structure problem* and *the categorisation problem*. These problems are primarily addressed in Chapter 3 and Chapter 5. The chapter also argues for how image schemas can be combined with one another to describe increasingly larger and more complex scenarios, a hypothesis that will be essential for upcoming chapters, in particular, for the ideas that are presented in Chapter 5.

Chapter 3: Formal Structure: Image Schemas as Families of Theories

In this chapter, image schemas are approached with the intention to provide a formal solution to the structure problem and the categorisation problem, introduced in Chapter 2. The main contribution of the chapter is to present how image schemas could be ontologically structured as interconnected families of theories. The structure problem is approached by clustering image schemas based on family resemblance and the categorisation problem is approached by ordering them in a hierarchy based on their internal complexity. The formal research is based on research findings in, first, developmental psychology which show how image schemas are conceptually 'fine-tuned' through the cognitive development, and second, cognitive linguistics which highlight the existence of multiple instances of the same or similar image-schematic structure in language. As a proof of concept, two image schema families are presented: the 'Two-Object' family, building on the image schemas Contact, Support and Link; and the 'Path' family which aims for a more extensive division of the Source_Path_Goal image schema. The selection of these two families is motivated as they capture the static relationships between objects and the dynamic relationships of object movement and, therefore, embody the notion that image schemas are spatiotemporal relationships.

Chapter 4: Introducing ISL^{FOL}: A Logical Language for Image Schemas

This chapter investigates how the abstract nature of image schemas can be formally approached and realised. In particular, the Image Schema Logic (ISL^{FOL}) is introduced as a formal language to describe the spatiotemporal dimensions found in image schemas. Inspired by previous research on formalising image schemas, the language is built on the Region Connection Calculus (RCC-8) as a method to formally deal with spatial regions and related object positions. Additionally, the Qualitative Trajectory Calculus (QTC) is used to describe relative movement between objects. As for the temporal dimension of image schemas, Linear Temporal Logic (LTL) is used as it provides a straightforward sequential representation for scenarios. Together these logical languages provide an expressive language to initiate the formal work on modelling the individual instances of image schemas. As a proof of concept, the Two-Object family and the PATH family from Chapter 3 are formally represented using ISL^{FOL} where each family member is extended axiomatically through the addition of spatial primitives.

Chapter 5: Modelling Conceptualisations: Combining Image Schemas to Model Event Conceptualisations

When introducing image schemas in Chapter 2, two aspects of the image schema combinations are highlighted. First, that complex image schemas often appear as combinations of several simpler image schemas. This is part of the work presented in Chapters 3-4. Second, conceptualisations of concepts and events can also be described using combinations of image schemas. In this chapter, formalised image schemas using the introduced ISL^{FOL} language are combined with one another to model simple events. Initially, the chapter introduces and names three different ways in which image schemas can be combined with one another: *merging*, *collection* and *sequential*. These are discussed as to how they relate to different concepts and events. As a proof of concept a formalisation of the dynamic aspects of CONTAINMENT are introduced. These are *Going* IN, *going* OUT and *going* THROUGH. Secondly, the chapter presents the more complicated events BLOCKAGE, BOUNCING and CAUSED_MOVEMENT which are formalised using the same method. Additionally, with the intention to position the presented research within work on artificial intelligence, the chapter discusses how combinations of image schemas can be used for formal commonsense reasoning.

Chapter 6: Generating Concepts: How Image Schemas Can Help Guide Computational Conceptual Blending

The chapter returns to the idea that image schemas are not only used for conceptualisations but also for concept invention. In Chapter 1, the theory of conceptual blending is introduced as a theoretical framework for creativity and concept invention built on the mechanisms of analogy. In conceptual blending, novel conceptual spaces, called *blends*, are the result of combining elements from two input spaces. While humans perform conceptual blending more or less effortlessly, for computational conceptual blending, one major problem exists. Namely, as the input spaces grow richer in information, so does the number of possible blends, most of which make little sense from a cognitive perspective. Inspired by analogy engines such as Heuristic Driven Theory Projection (HDTP) and computational systems capable of conceptual blending such as Heterogeneous Tool Set (Hets), this chapter proposes how the conceptual information found in image schemas could guide the blending procedure. This is done on three levels. First, as image schemas are rich in conceptual information, by assigning the information encoded in an image schema higher priority to be inherited into the blended space. Second, inspired by how image schemas often provide the information skeleton in analogies, let the image schemas compose the generic space. Additionally, as similar image schemas can be structured in hierarchical families of theories, as demonstrated in Chapter 3, the blending procedure can make use of this to find previously unidentified similarities between the input spaces by either strengthening or weakening the input spaces in terms of image-schematic information. The chapter provides several examples in which these ideas are explored and visualised.

Chapter 7: Defining Concepts: Experiment on the Role of Image Schemas in Object Conceptualisation

This chapter presents the first of the two empirical chapters. It aims provide support for the ideas presented in Chapter 2 and the research conducted in Chapter 5 and Chapter 6 in which image schemas are argued to, on different levels, be conceptual building blocks for concepts and events. In order to strengthen this foundation, an experimental study was performed in which 21 participants were asked to assign image schemas to 44 everyday objects. The participants were selected using a convenience sampling and divided into two groups: one group that was presented with eight (plus a 'none' option) of the most commonly mentioned image schemas and another group that was presented with sketched illustrations of the same image schemas. The participants were then asked to assign these image schemas to 44 objects presented on flashcards while providing a written motivation for how they had reasoned. The motivations given by the participants demonstrated that approximately 2/3 of the assigned image schemas were assigned by mapping the object to the spatiotemporal dimension construing the image schemas, providing a reliable foundation for the rest of the results. Regarding the assigned image schemas, the experiment showed a great overlap between the assignment of the participants to a control group of image schema researchers, providing further support that image schemas lie at the core of the objects and are not arbitrarily assigned. Another conclusion that can be drawn from the experiment is that image schemas are more intuitively assigned to the simpler objects than for the increasingly complex objects, where combinations of image schemas became more prominent. This is an interesting result as it provides empirical support for some of the ideas that are presented in Chapter 5.

Chapter 8: Identifying Image Schemas: Experiment Towards Automatic Image Schema Extraction

Most of the chapters assume that image schemas are already defined both in a formal language as well as in natural language. However, before any of the theoretical suggestions are able to make an impact on the advancement of artificial intelligence and natural language processing, a method to identify image schemas in natural language is needed. As of yet, no such method exists. Therefore, the chapter presents an experiment which takes the first steps towards an automatic method to identify image schemas from a natural language corpus. The experiment is built on syntactic pattern matching, where linguistic expressions associated to the Source_Path_Goal schema are searched for in the InterActive Terminology for Europe (IATE), a multilingual terminology database, in the four languages English, German, Swedish and Italian. These extracted expressions are aligned across the languages and are then identified in their sentence structure to determine their accuracy as image-schematic and on which level of the Path family, introduced in Chapter 3, they belong.

The results illustrate the complexity of identifying spatiotemporal expressions in natural language as only 1/3 of the extracted expressions were deemed to belong to the intended Path family. However, despite the complexity of the task, the results provide empirical support for the existence of a hierarchical Path family, as introduced in Chapter 3, and also provide arguments for the family to be extended by Path members previously not considered.

GitLab Repository

In addition to the content in these chapters, a repository of all the formalised image schemas and their combinations can be found in

Appendix A: GitLab Image Schema Repository and on:

`https://gitlab.com/tillmo/ISL.git`

1

Creating Concepts: Considerations from Psychology and Artificial Intelligence

Cogito ergo sum

René Descartes
Discours de la méthode, 1637

Content and Context

The symbol grounding problem is a prototypical problem in cognitive science and concerns how symbols gain their meaning. In this chapter, the symbol grounding problem is discussed with the purpose to address the missing step for how artificial intelligence research can approach conceptual understanding and concept invention. A potential solution to the symbol grounding problem is offered through the theory of embodied cognition. One important aspect is Moravec's paradox, which states that high-level cognition such as calculation and memory require fairly little computer power, whereas low-level cognition such as sensorimotor processes, require substantially much more. Additionally, the chapter introduces the state of the art in relevant research on creativity and concept invention from a cognitive perspective in order to lay the foundation for successive chapters.

The chapter includes considerations on and discussion of:

- Artificial life
- Symbol grounding problem
- Embodied cognition
- Knowledge representation
- Creativity and concept invention
- Information transfer
- Conceptual blending

1.1 Setting the Scene

1.1.1 On Creating Artificial Life and Intelligence

> It was on a dreary night of November that I beheld the accomplishment of my toils. With an anxiety that almost amounted to agony, I

> collected the instruments of life around me, that I might infuse a spark of being into the lifeless thing that lay at my feet.
> - Mary Shelley, *Frankenstein*

The creation of life is a mystery that has kept the human mind busy since the dawn of cognitive thinking. All major religions have a creation story in which a divine spirit (or aliens) brings forth life on earth. Myths and legends speak of humans giving life to golems and homunculi and literature and pop-culture introduce monsters, living dead and robots that may not only take over the world, but become conscious and sentient. Perhaps the mystery of life, in particular, the desire to create it, lay in the endeavour to build a *Tower of Babylon* and to play God, perhaps it is to create a companion or to build a slave, perhaps it is simply to better understand what we are and where we come from. Regardless of reason, what once were the stuff of dreams and science-fiction is now something that modern science is slowly tapping into.

The introduction starts with a quote from Mary Shelley's *Frankenstein, or The Modern Prometheus*, in the scenario in which Dr Frankenstein is about to give life to a lifeless creature. While the likes of Dr Frankenstein might appear comical and ridiculous in a scientific context, biologists can now manipulate DNA through CRISPR techniques [1], allowing the transfer of genetic properties from one species into another. Research programs such as these can bypass natural evolution and generate 'new life' through innovative scientific methods. If biologists are concerned with the physical and biological aspects of generating new life, it has been up to the computer scientists to construct a mind.

Since the birth of modern computer science, one goal was to simulate human cognition, namely to create artificial intelligence. Computationally storing memory and performing calculations were some of the earliest signs of the emergence of artificial intelligence, and today there exist complex computer systems that successfully perform increasingly advanced tasks like face recognition, predicting outcomes in world politics, beating the world champions of games like Chess and Go, trading on the stock market and your next favourite film may be introduced to you by a recommender system. Despite the remarkable progress seen in artificial intelligence and computer systems, through among other the development of cognitive computing and the increased understanding of human cognition, one thing that neither biologists nor researchers of artificial intelligence have managed to simulate is the 'human soul'.

Regardless if you believe in the existence of an actual soul or not, one category of cognitive phenomena remains an issue for artificial intelligence research to simulate. Some of the phenomena belong-

[1] Le Cong, F. Ann Ran, David Cox, Shuailiang Lin, Robert Barretto, Naomi Habib, Patrick D. Hsu, Xuebing Wu, Wenyan Jiang, Luciano A. Marraffini, and Feng Zhang. Multiplex Genome Engineering Using CRISPR/Cas Systems. *Science*, 339:819–823, 2012

ing to this group are emotions, contextual appropriateness, natural language understanding and generation, and creativity. Creativity is a particularly difficult field of research as it is an umbrella term for many cognitive processes that are still largely undefined. Naturally, if it is uncertain how human creativity works, it can be argued that the artificial simulation thereof is not any easier. An additional problem is that even the simplest of artificial systems, consisting of only a few lines of code, a few grammatical rules and a database of words, can randomly generate a poem, yet humans are often unwilling to prescribe this kind of performance any creative ability [2]. For creative ability, the presence of something more, something like a 'soul', appears to be required for a human to acknowledge that a product is the result of a creative or innovative process.

Perhaps biased by his time's culture and religious views, Descartes proclaimed a classic view of the soul and spoke of the *Body-Mind Problem*. Still today this remains an open issue in philosophy and cognitive science as a whole, namely the relationship between the internal mind and the external body. The problem has been approached somewhat differently throughout the decades and it can be argued it has been rephrased by Harnad [1990] into the *Symbol Grounding Problem*. This rephrasing allows the researcher to ignore all the problems that arise when trying to define something as abstract, elusive and religiously infused as a *soul*, or even a *mind*, by refocusing the problem to how symbols in the world (e.g. words, signs, pictures and behaviours) gain their meaning.

In the next section, this problem is introduced properly.

1.1.2 The Symbol Grounding Problem

One of the prototypical problems in cognitive science, linguistics, and artificial intelligence is the symbol grounding problem. Simply put it deals with the question of how symbols acquire meaning. More formally the problem can be summarised as Harnad [1990, p. 335] describes it below:

> How can the semantic interpretation of a formal symbol system be made intrinsic to the system, rather than just parasitic on the meanings in our heads? How can the meanings of the meaningless symbol tokens, manipulated solely on the basis of their (arbitrary) shapes, be grounded in anything but other meaningless symbols?

One of the most famous critiques to the development of (strong)[3] artificial intelligence that brought forth the symbol grounding problem, is the thought experiment *The Chinese Room* introduced by Searle [1980]. In his seminal paper, Searle uses an analogy in which a person is isolated in a room where different signs enter the room from

[2] Simon Colton and Geraint A. Wiggins. Computational creativity: The final frontier? *Frontiers in Artificial Intelligence and Applications*, 242:21–26, 2012

[3] Proclaimers of strong AI, or *Artificial General Intelligence* (AGI) as it also is called, defend the view that a system is a 'mind of its own' and can be claimed to understand and experience cognitive states. In opposition, weak AI supporters suppose that artificial systems can only 'illuminate' human behaviours.

one direction. The person's purpose is to 'rewrite' these signs following a set of rules before returning them to the outside in another direction. What the person is unaware of is that the signs actually are Chinese characters constructing fully comprehensible sentences. Thus by following the instruction rules the person ends up 'communicating' in Chinese. At this revelation, Searle proceeds to ask the reader: "Does the person in the room speak Chinese?" Most of us would probably intuitively take Searle's stance and argue that the person in the room does not speak Chinese because a fundamental part of cognition is missing. One suggestion of what is missing is *intentionality*[4]. In this setting, the Chinese characters lack meaning to the translator. The general consensus to explain this intuition is that symbols do not acquire meaning solely in relation to other symbols.

In linguistics, the symbol grounding problem is often discussed in relation to *The Semiotic Triangle*, or the triangle of reference, see Figure 1.1 [5]. The semiotic triangle highlights the problem of how the real world *referent* relates to its symbolic *representation* and the mental *concept*. This differs from the symbol grounding problem as it does not abstract away from the mental representation, but include a neuro-cognitive domain as well.

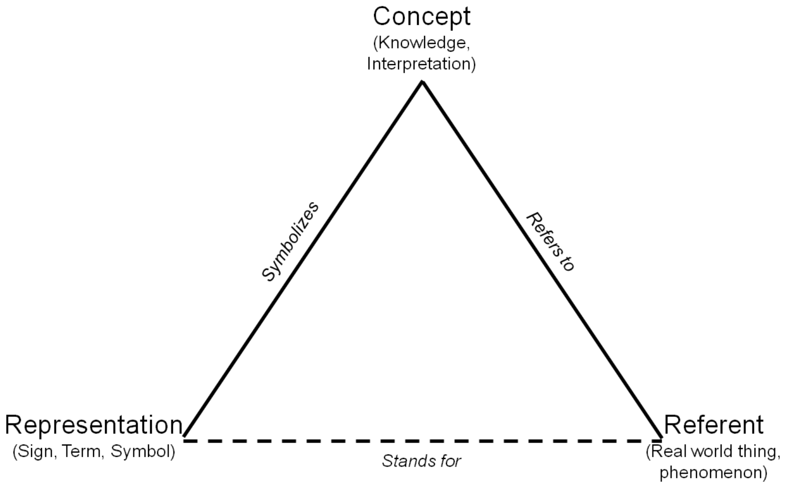

Figure 1.1: The Semiotic Triangle

The view of cognition has undergone many paradigm shifts through the years. The classic view *Computationalism* or 'cognition is computing' was introduced alongside the birth of computer science through the ideas of Newell and Simon [6]. While this provided excellent growing grounds for the initiation of research on artificial intelligence, it proved difficult to explain not only the symbol grounding problem within this framework, but also the human mind as a whole. It appears as though the human mind does not act in the

[4] Intentionality is the power of minds to be about, to represent, or to stand for, things, properties and states of affairs [Jacob, 2014].

[5] Charles Kay Ogden and Ivor Armstrong Richards. International library of psychology, philosophy and scientific method. Harcourt Brace Jovanovich, 8 edition, 1989

[6] Howard Gardner. *The Mind's New Science: A History of the Cognitive Revolution.* Basic Books, New York, 1985

logical way imposed by computationalism. One group of theories for cognition that has been growing in influence is those build on the *Embodied Mind Hypothesis* [7].

In the next section these two views of cognition with emphasis on the embodied mind hypothesis will be discussed as this provides an interesting stepping stone towards solving parts of the symbol grounding problem that was introduced in this section.

1.1.3 Computationalism vs. Embodied Cognition

In the cognitive sciences, the view of cognition has undergone several paradigm shifts during the last century. Initiating the birth of computer science, the traditional view of cognition held the notion that 'cognition is computing'. The idea was that the brain worked as a direct storage facility for memories and mental representations and cognition was simply performing computations and calculations on these mental symbols. As computers were invented it was believed that human-level artificial intelligence (AGI or Strong AI) was just around the corner and would be integrated into our societies within a couple of decades [8].

One of the reasons why the development of artificial intelligence has taken longer than initially expected is due to the complexity to build computer processing power that can match a human mind in speed and capacity as initially estimated by von Neumann [1958]. Today some supercomputers exceed human brain power in many regards, yet we are still not able to speak of human-level artificial intelligence. For some reason, it appears as though computing power that corresponds to, or approximates, 'brain power' does not result in an artificial agent that is equal to the range of flexibility and adaptability that human intelligence display. As Moravec's [1988] paradox states, it has been demonstrated to be fairly straightforward to model high-level computation and reasoning that are difficult for human adults, but to model the low-level sensorimotor skills found in early infancy requires much more computational power. Another reason for this 'delay' is due to that the premise 'cognition is computing' appears to be incorrect. The human mind does not seem to function in the binary, logical way that the pure reasoning behind computationalism implies.

Throughout the decades that followed Simon and Newell and the introduction of computer science, the view of cognition has gone through many stages; e.g. *Behaviourism*, *Connectionism*, and recently the research field has taken a liking to theories building from the concept of an *Embodied Mind* where deep learning is showing impressive results for the advancements of computer science.

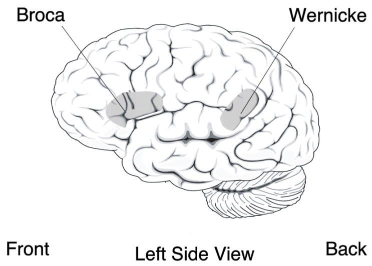

Figure 1.2: Broca's and Wernicke's Area

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[7] Lawrence Shapiro. *Embodied Cognition*. New problems of philosophy. Routledge, London and New York, 2011

[8] Howard Gardner. *The Mind's New Science: A History of the Cognitive Revolution*. Basic Books, New York, 1985

The embodied theories partly come from the last decades' research findings in neuroscience. Through case studies and modern neuroimaging (NI) techniques the roles of different brain regions are constantly being deciphered. For example, the different neural structures found in the *Brodmann's Areas* (BA) [9], and *Broca's* and *Wernicke's Areas* (roughly corresponding to BA 44-45 in the inferior frontal gyrus and BA 22 in the superior temporal gyrus, see Figure 1.2.) can be identified together with their functions in human cognition; language processing respective language production. Hence, gaining information regarding human cognition is no longer only possible through traditional psychology and linguistic research methods. In particular, the development of NI allowed the emerging field of psycholinguistics to investigate the mental role of symbols' meanings. Research findings started to demonstrate neural activation in the sensorimotor cortex also when the body was at rest and only words were presented. For example, Tettamanti et al. [2005] found that listening to action related words produce neural activation in the motor cortex. Further, investigations on patients suffering from *Neural Motor Disease* demonstrate a clear connection to language dysfunction [10].

From findings such as these theories of cognition emerged that emphasise sensorimotor processes as the source for cognitive development and concept formation [11,12]. The theory is supported by independent findings from several disciplines including cognitive linguistics, psychology and neuroscience (e.g. Gallese and Lakoff [2005], Feldman and Narayanan [2004], Wilson and Gibbs [2007], Louwerse and Jeuniaux [2010], Gibbs [2006]). Despite the support, there are still conflicting views as to which degree cognition is embodied. For instance, Tomasino et al. [2014] found that while the motor cortex is activated upon processing action verbs, the activation could not be found when the same verbs were used in an abstract setting. This by necessity means the existence of a semantic distinction in words given them being used in a concrete or an abstract sentence (see Aziz-Zadeh and Damasio [2008] for a more comprehensive overview on *Embodied Semantics*.). Additionally, it has been shown that extreme forms of embodied theories, in which meaning is directly connected to the neural activation, are as incomplete as extreme forms of disembodied theories, in which no connection to the nervous system is implied [13].

While this is a problem to be solved in the cognitive sciences, for knowledge representation in artificial intelligence this uncertainty is not a breaking point. Instead, the embodied mind hypothesis serves as a potential growing ground in which it may be possible to approach the symbol grounding problem. If cognition comes as a direct consequence of the body's interactions with the environment, this

[9] Korbinian Brodmann. *Vergleichende Lokalisationslehre der Grosshirnrinde in ihren Prinzipien dargestellt auf Grund des Zellenbaues*. Verlag von Johann Ambrosius Barth, 1909

[10] Thomas H. Bak and John R. Hodges. The effects of motor neurone disease on language: Further evidence. *Brain and Language*, 89:354–361, 2014

[11] Lawrence Shapiro. *Embodied Cognition*. New problems of philosophy. Routledge, London and New York, 2011

[12] George Lakoff and Mark Johnson. *Philosophy in the Flesh*. Basic Books, 1999

[13] Lotte Meteyarda, Sara Rodriguez Cuadradob, Bahador Bahramic, and Gabriella Viglioccoa. Coming of age: a review of embodiment and the neuroscience of semantics. *Cortex*, 48: 788–804, 2012

means that there is a concrete method to interpret the connection between the real world *referent*, the symbolic *representation* as well as the mental *concept*. In terms of artificial intelligence, this provides a practical foundation to approach simulations of cognitive phenomena.

In the next section some foundation to knowledge representation will be introduced on which this foundation can be artificially approached.

1.2 Knowledge Representation

1.2.1 Moravec's Paradox and the Persistance of Formal Logic

One of the major problems for cognitively inspired artificial intelligence is how to formally represent cognitive phenomena. Classic artificial intelligence research builds on formal languages such as mathematics and logic. These languages are rigid and inflexible and given the rejection of computationalism as the primary view of cognition, more cognitively inspired computational methods have been developed. Simulating Hebbian learning (as discovered by Hebb [1949]) under the premise that 'cells that fire together, wire together', are Neural Networks (NN) and more recently the statistic way the brain appears to function can be found in similar machine learning approaches. For instance, the work by Regier [1996] demonstrates how NNs can be used to model the early stages of human cognition. While it is tempting to turn to machine learning when formally approaching embodied cognition, it does have certain disadvantages.

In the 1980's Moravec pinpointed one of the biggest paradoxes in the advancement of artificial intelligence. Namely, that for high-level cognition, difficult even for human adults, such as memory capacity and accuracy and speed of calculations, formal systems require fairly little computer power, when at the same time, modelling the low-level cognitive phenomena in the sensorimotor system that even infants master, substantial computational efforts are required. In Section 1.4.1 two categories of processes involved in learning concept will be discussed, distinguishing between perceptual and conceptual processes. Naturally, a neural network would be more suitable to simulate the perceptual, learning processes of concept emergence. However, it is not necessarily the same for the conceptual, more descriptive, processes. When the perceptual processes are determined by repeated stimuli into generalisations, the connection between these generalisations to actual concepts, might benefit from a more descriptive form of representations. While the conceptual processes are built on generalisations from the perceptual processes, that can be approached through, for instance, deep learning, the conceptual processes would be better put to use in a more classic logical fashion. By formally representing mental concept such as image schemas, formal knowledge representation allows for them to be designed to match the human correspondence found in language and developmental psychology. This is beneficial when dealing with natural language understanding. Additionally, by representing them in accordance to previous research on concept invention they can easier be integrated into the pre-existing body of work. Naturally, for a computational system to master both sets of processes a combination of classic knowledge representation and cognitive computing would be preferred [14].

Following the reasoning outlining this chapter, it appears as though it is not beneficial to completely reject the notion of symbolic representation in terms of classic logical representations. Embodied cognition, the symbol grounding problem and the semiotic triangle all illustrate that while mental representation may take the form of neural activation it is not unreasonable to describe this activation in a more concrete fashion than what is currently possible through NN and deep learning.

One important aspect of knowledge representation is how to build an appropriate knowledge structure, an *ontology*, which will be introduced in the upcoming section.

1.2.2 Ontology

Originating from philosophy, ontology is the study of the nature of being and the relations between different categories of the world. It deals with concepts, their roles, and relationships that connect the different concepts present [15]. In the classic sense, ontology concerns the nature and structure of reality. When learning concepts, categories are a natural aspects of the nature of to describe and relate concepts. For cognitive phenomena there is no difference, as ontological structure also provides a more reliable description for involved concepts.

In AI ontologies provide a method to structure all the data a system has access to. To structure known objects, or concepts, their attributes and their relationships. The backbone of an ontology is the taxonomy, which deals with precisely this issue.

Ontologies come in different categories, upper level, or foundational ontologies, aims to generate a general model for the world in which many scenarios fit in. One example is the Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE) [16] which aims to be cognitively accurate in capturing the underlying categories found in natural language and commonsense. Generalized Upper

[14] Tarek R. Besold, Artur d'Avila Garcez, Sebastian Bader, Howard Bowman, Pedro Domingos, Pascal Hitzler, Kai-Uwe Kühnberger, Luis C. Lamb, Daniel Lowd, and Priscila Machado Vieira Lima. Neural-symbolic learning and reasoning: A survey and interpretation. *arXiv preprint arXiv:1711.03902*, 2017a

[15] Nicola Guarino, Daniel Oberle, and Steffen Staab. What Is an Ontology. In S. Staab and R. Studer, editors, *Handbook on Ontologies*, pages 1–17. Springer Berlin Heidelberg, 2003

[16] Stefano Borgo and Claudio Masolo. Foundational Choices in DOLCE. In *Handbook on Ontologies*. Springer, 2010

Model Knowledge Base (GUM) [17] is another ontology that aims to assist natural language processing systems by accessing the categorical information presented.

1.2.3 The Reusability and Interoperability Problem

While the use of ontologies varies considerably, there are two recurring challenges: *reusability* and *interoperability*.

Reusability is an issue because the development of ontologies is typically done manually by experts and, thus, is an expensive process. Hence, it is desirable to be able to reuse existing ontologies during the development of new ontologies. This presupposes a framework that allows to build *structured ontologies* by identifying modules and their relationships to each other. For example, it requires the ability to combine two existing ontologies in a way that handles the namespaces of the ontologies in an appropriate way. Further, the reuse of an existing ontology often requires that the ontology is adapted for its new purpose. For example, the adaption may require the extension of the ontology by new axioms, or the extraction of a subset of the ontology, or the change of its semantics from open world to closed world.

The interoperability challenge is closely related to the reusability challenge. Since the development of ontologies is not an exact science and is usually driven by project specific requirements, two ontologies that have been developed independently will represent the same domain in different and, often, conflicting ways. Thus, in a situation where two independently developed ontologies are supposed to be reused as modules of a larger ontology, the differences between these ontologies will typically prevent them from working together properly. Overcoming this lack of interoperability may require an alignment or even an integration of these ontologies. This typically involves the identification of synonyms, homonyms, and the development of bridge axioms, which connect the two ontologies appropriately.

1.2.4 The Distributed Ontology, Model and Specification Language: DOL

Addressing the two challenges presented above, there is a diversity of notions providing design patterns for and interrelations among ontologies. The *Distributed Ontology, Model and Specification Language* (DOL) aims at providing a unified metalanguage for handling this diversity. In particular, DOL enjoys the following distinctive features:

- structuring constructs for building ontologies from existing ontologies, like imports, union, forgetting, interpolation, filtering, and

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[17] John A Bateman, Bernardo Magnini, and Giovanni Fabris. The generalized upper model knowledge base: Organization and use. *Towards very large knowledge bases*, pages 60–72, 1995

open-world versus closed-world semantics;

- module extraction;
- mappings between ontologies, like interpretation of theories, conservative extensions etc.;
- alignments, interpretations, and networks of ontologies;
- combination of networks.

DOL is a metalanguage that allows the specification of (1) new ontologies based on existing ontologies, (2) relations between ontologies, and (3) networks of ontologies, including networks that specify blending diagrams [18]. These diagrams encode the relationships between the base ontology and the (two or more) input spaces. The blending diagrams can be executed by the *Heterogeneous Tool Set* (HETS), a proof management system. HETS is integrated into Ontohub[19], an ontology repository which allows users to manage and collaboratively work on ontologies. DOL, HETS, and Ontohub provide a powerful set of tools, which make it easy to specify and computationally execute conceptual blends, as seen for instance in the work by Neuhaus et al. [2014]. An extensive introduction to the features and the formal semantics of DOL can be found in [Mossakowski et al., 2015a].

DOL and its structuring language are designed as a multi-logic meta-language, already supporting all of the mainstream ontology languages in use today.

As symbol grounding is approached not only for the sake of concept *representation* but also for concept *generation*, the next section is intended to introduce concept invention in the umbrella setting of *Creativity*.

1.3 Creativity

Simplified, creativity is the cognitive mechanism to generate novel concepts, products and/or ideas. While there are a multitude of theories that aim to address the cognitive process behind creativity, the scientific investigation thereof encounters many problems. For instance, neither does a complete understanding of what creativity is exist, nor an understanding of how it manifest. In fact, as of yet, there is no agreed on definition of creativity. Despite this, plenty of research has been conducted on this elusive topic, both from an cognitive perspective (e.g. Csikszentmihalyi [2014], Sawyer [2011], Runco [2014]) as well as a computational one (e.g. Wiggins [2006], Besold et al. [2015], Boden [1998]).

[18] Blending diagrams are built from the premise of the theory of Conceptual Blending which is introduced later in this chapter.

[19] `http://www.ontohub.org`

Creativity is found in many different domains: arts, music, dance, science, everyday problem-solving, etc., and naturally this requires not only different bodily skills but also different cognitive skills. Simultaneously, insight and novel discovery are as important as accessing existing knowledge and memory in the development of new theories and ideas [20]. There is no questioning that creativity is a form of higher cognition, as creative processes involve a collaboration of several cognitive functions [21]. This is supported by results from neuroscience showing activation the pre-frontal cortex during creative tasks, an area which is known to orchestrate higher functions [22].

The study of creativity was initially pursued in much the same as the study of intelligence. The desire was to evaluate human creativity by means of a *Creativity Quotient*, similar to the more famous *Intelligence Quotient* [23]. However, this was early deemed to be more difficult than expected due to the multidimensional character of creative capacity. While there are tests designed to measure creative capacity and thinking (e.g. Torrance's test for creative thinking [24]) that, in particular situations, may be used to detect a person's capacity for creative and divergent thinking, the notion of a creativity quotient has been left to the history books. Instead, much of the research is performed on which cognitive components underlie creativity. Traditionally creativity was considered to be an associative process. In the 1960's Mednick [1962] introduced this under the *Associates Theory* and describes the creative process with the following words [p. 221]:

> ... we may proceed to define creative process as the forming of associative elements into new combinations which either meet specified requirements or are in some way useful.

However, it has been increasingly clear that the creative process is a combination of divergent and convergent processes as creativity relies on both of these modes of thought as introduced by Guilford [1967].

In *Divergent Thinking*, often referred to as 'associate thought', associations are allowed to flow freely to find related concepts to the original problem or thought pattern. It is a process in which a problem is solved by defocussing from the actual problem and letting the mind flow and make associations, not rarely through analogies. The derived solution might be one of many possible ones and there is no one right answer. It deals with finding relationships and similarities between concepts and items where previously no connection existed [25]. Concrete examples of divergent thinking processes would be to 'brainstorm' or to draw 'mind maps' in which a person associatively explores the conceptual space of a particular topic.

On the opposite resides *Convergent Thinking*, or 'analytical thought'. It focuses thoughts on what is already known. Thoughts are focused

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[20] Rex E. Jung, Charles Gasparovic, Robert S. Chavez, Ranee Flores, Shirley M. Smith, Arvind Caprihan, and Ronald Yeo. Biochemical support for the "threshold" theory of creativity: a magnetic resonance spectroscopy study. *The Journal of neuroscience*, 29(16): 19–25, 2009

[21] Mark A. Runco and Ivonne Chand. Cognition and creativity. *Educational Psychology review*, 7(3):243–267, 1995

[22] Arne Dietrich. The cognitive neuroscience of creativity. *Psychonomic bulletin & review*, 11(6):1011–26, 12 2004

[23] Nancy C. Andreasen. *The Creative Brain: The Science of Genius*. Plume, New York/Washington, D.C., 2006

[24] Ellis Paul Torrance, Orlow E Ball, and H Tammy Safter. *Torrance tests of creative thinking*. Scholastic Testing Service, 2003

[25] Liane Gabora. Revenge of the "neurds": Characterizing creative thought in terms of the structure and dynamics of memory. *Creativity Research Journal*, 22(1):1–13, 2010

at the problem at hand, for which there is only one correct solution. By analysing the problem through symbol manipulation and using deductive laws of cause and effect, the one correct, or optimal, solution will be arrived at [26].

These two modes of thinking are thought to work in a recursive process where you zoom in and out from a particular problem or situation.

The classic explanation for the existence of creative thinking is that creativity is a form of problem-solving [27]. It is in an encounter with a problem, when the routine behaviour no longer can be applied, that we display creative behaviour [28,29]. In artistic domains, this statement might feel misplaced as much of visual and auditory creativity appears to focus more on either spreading a message (or feeling) rather than solving a particular problem. However, for everyday creativity, it is clear that it is in unfamiliar situations that the most creative 'out of the box' solutions are presented.

Analogical thinking is an essential aspect of creativity. The core of analogy is to transfer knowledge to an unknown domain by using already existing knowledge. While this is considered a controlled method, it has been found that novices use far more creative solutions in analogical reasoning than that found by experts [30]. The role of analogy in creative thinking will be further elaborated in a later section.

In the field of artificial intelligence, creativity has been designated to be 'the final frontier' [31]. Despite all the uncertainties found in research on creativity, *Computational Creativity* (CC) has become its research field of its own. For CC the notion of 'creativity' is typically understood as a cognitive process defined and evaluated based on the *degree of novelty* and *usefulness* of the resulting artefact [32,33]. Naturally also the process by which creativity is expressed is relevant. However, since the cognitive mechanisms behind creativity remains a black box, CC has (out of necessity) primarily focused on the requirements of the product. CC has seen significant progress in the last decades. Using a variety of artificial intelligence techniques there are now a multitude of systems that paint, write poems and solve problems (see Besold et al. [2015] for an overview). However, as the research field of computational creativity learnt the hard way: humans guard their creativity, both eagerly and jealously [34] [35]. Much like human-levelled artificial intelligence is not reached, neither is the creative capacity.

Creativity is a large research field with many different topics and sub-disciplines. One of these disciplines is *Concept Invention*. It concerns the research question of how concepts can be learned from the environment, but more importantly also how they themselves are

[26] Liane Gabora. Revenge of the "neurds": Characterizing creative thought in terms of the structure and dynamics of memory. *Creativity Research Journal*, 22(1):1–13, 2010

[27] Herbert A. Simon. Creativity and motivation: A response to Csikszentmihalyi. *New Ideas in Psychology*, 6(2): 177–181, 1 1988

[28] Steven M. Smith, Thomas B. Ward, and Ronald A. Finke. *The creative cognition approach*. MIT Press, 1995

[29] Mihaly Csikszentmihalyi. The flow experience and its significance for human psychology. In M. Csikszentmihalyi and I. S. Csikszentmihalyi, editors, *Optimal experience: Psychological studies of flow in consciousness*, pages 15–35. Cambridge University Press, 1988

[30] Yukari Nagai. Concept blending and dissimilarity: factors for creative concept generation process. *Design Studies*, 30:648–675, 2009

[31] Simon Colton and Geraint A. Wiggins. Computational creativity: The final frontier? *Frontiers in Artificial Intelligence and Applications*, 242:21–26, 2012

[32] Mark A. Runco and Garrett J. Jaeger. The standard definition of creativity. *Creativity Research Journal*, 24(1):92–96, 2012

[33] Margaret A. Boden. Computer models of creativity. *AI Magazine*, Fall 2009

[34] Simon Colton and Geraint A. Wiggins. Computational creativity: The final frontier? *Frontiers in Artificial Intelligence and Applications*, 242:21–26, 2012

[35] Simon Colton. Creativity versus the perception of creativity in computational systems. In *AAAI spring symposium: creative intelligent systems*, volume 8, 2008

invented. The next section is devoted to this research area.

1.4 Concept Invention

Research on concept formation is tightly connected with developmental psychology and cognitive linguistics, but it has also seen an increase in artificial intelligence through *Computational Concept Invention*. To understand concept invention, the associated theories *Conceptual Metaphor Theory* and *Conceptual Blending* will be introduced as to how they relate to creativity.

Within the field of creativity, concept invention is one of the most important aspects from a more linguistic point of view. Arguably children are creative in their word use and their ability to invent words to fit the content of conversation and to express their desires. By using a limited skill set they can still communicate with their parents or other adults to express what they want and what they mean.

Even among adults, concept invention can be argued to be one of the highest forms of not only creative ability but also signs of intelligence. Puns, poetry and jokes are perfect examples of concept invention and creative word use.

1.4.1 Learning and Inventing Concepts

Before diving into the complicated aspects of concept invention some key features of language development need to be established.

While language learning obviously is a process that involves a lot of linguistic input from the environment (in particular from parents and close relatives) there are two major accounts suggested as to how syntax is developed.

The first is the empiricist account, namely that solely listening to language is enough to learn grammar as well as concept and object names. The second, introduced by Chomsky [2014], is the nativist account that proclaims an innate grammar. According to Chomsky, there is a particular part of the brain (the Language Acquisition Device (LAD)) that is responsible for grammatical development. While the Chomskian view has some advantages, the framework behind embodied cognition suggests instead that language (in the ways that counts) more likely is constructed rather than innate.

While it is common to in computational domains to speak of concept formation, or computational concept formation as a creative ability, it is not exclusively so. Concept formation is not solely the ability to generate novel concepts, it also includes a whole range of cognitive abilities that stretches from perceiving the world, abstracting relevant information and through language or other means of expression provide titles and names to perceived concepts and experiences.

Developmental psychologist Mandler [2004] investigates cognitive development and concept formation in the 'sensorimotor period'[36] during early infancy. In the paper series *How to build a baby I* [37], *II* [38] and *III* [39], Mandler studies this relationship between perception and concept invention. One important point Mandler makes is that perceptive characteristics such as shapes may be important for categorisation but they appear to be, not in themselves, part of concepts and their meaning. For example, a particular shape might be a typical but not an essential property of an exemplary. This discrepancy between perception and conceptualisation is further developed in [Mandler, 2009], where she distinguishes two categories of cognitive processes that take place during concept formation: perceptual and conceptual processes. These two categories contain vital distinctions and will be further discussed below.

The Perceptual Process

The first, the *Perceptual Process*, is seen to be responsible for *object categorisation* based on similarity. Here the shape of objects plays a central role. For example, infants can early on distinguish between animals such as dogs and birds, but it takes much longer before they consistently and correctly categorise and distinguish between animals that exhibit greater similarity such as cats and dogs [40].

There are several theories that aim to explain the perceptual mechanisms behind concept formation. Some are introduced below.

Prototype Theory: Is based on the hypothesis that all object categories are built from prototypes derived from experience [41]. Perceptions are categorised into a particular group if they sufficiently resemble the prototype. An example is 'dog'. There are many dog breeds that often greatly differ visually from each other. Still, (in most cases) people can intuitively relate instances they encounter, to the generalised version of their 'prototypical dog'.

Recognition-by-components Theory: The theory aims to identify visual components that are abstracted from the prototype[42] [43]. It is built on the idea that objects are constructed by a limited number of 2D or 3D geometric shapes called *geons* (see Figure 1.3 for examples). When these geons are combined with one another a more holistic shape comes to be and this is the foundation for object recognition. Originally there were considered to be 32 geons but this has been up for debate.

[36] The sensorimotor period is estimated to the first two years in which a child predominantly learns by exploring through means of their physical body [Piaget, 1952].

[37] Jean M. Mandler. How to build a baby: On the development of an accessible representational system. *Cognitive Development*, 3(2):113–136, 1988

[38] Jean M. Mandler. How to build a baby: II. Conceptual primitives. *Psychological review*, 99(4):587–604, 1992

[39] Jean M. Mandler. How to build a baby: III. Image schemas and the transition to verbal thought. *From Perception to Meaning: Image Schemas in Cognitive Linguistics*, (January):137–163, 2005

[40] Denis Mareschal and Paul C. Quinn. Categorization in infancy. *Trends in Cognitive Sciences*, 5(10):443–450, 2001

[41] Eleanor Rosch and Carolyn B. Mervis. Family resemblances: Studies in the internal structure of categories. *Cognitive Psychology*, 7(4):573–605, 1975

[42] There are also a significant amount of non-visual attributes that are included in the prototype. However, these will be addressed later on.

[43] Irving Biederman. Recognition by components: A theory of human image understanding. *Psychological Review*, 94 (2):115–117, 1987

An example of how recognition-by-components theory works is to break down a coffee cup into two geons. Namely, a hollow *cylinder* with *handle* on one side (see Figure 1.4). This can be extended to more complex objects. E.g. the 'prototypical dog' from above might be a particular construction of a *cylinder* for a torso, four *expanding cones* representing legs, an *expanding handle* for a tail and an *ellipsoid* for a head. Each of these parts can be divided to capture more details, e.g. *cones* for ears, creating a more detailed spatial description and/or ontology based on geons.

However, the visual description does not, as Mandler points out, in itself carry the nature of the object. To ascertain the usage and roles of an object, such as a coffee cup, where the capability to *contain* liquids is paramount, a different approach is required.

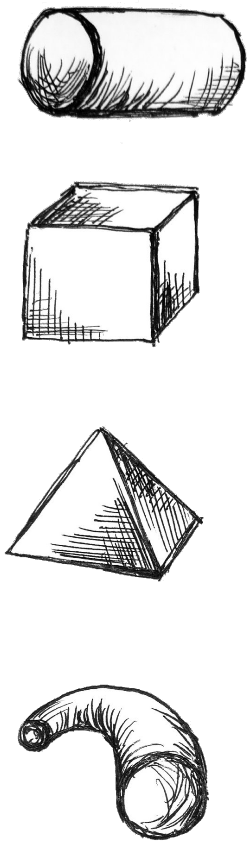

Figure 1.3: Example of Geons. From the top: Cylinder, Cube, Pyramid and Expanded Handle.

The Conceptual Process

The second category of components of Mandler's notion of concept formation is the *conceptual process*, during which the purpose and usage of objects are established [44]. Here, the role of shape and visual characteristics is less clear, and instead, possible uses, affordances and purposes of the objects play the central roles. Below two central theories for this are introduced.

Affordance Theory: The theory proposes that all object meaning is not defined by the visual characteristics found in recognition-by-components and similar ideas, but rather that meaning is in the 'usages' and the 'purposes' of objects [45]. Gibson calls these usages 'affordances'. To illustrate, the essential property of a coffee cup is that it can *contain* liquids (in this case particularly coffee), and for a vehicle, the most paramount characteristic is that it needs to be able to offer transportation. If these affordances are absent, the conceptualisation needs to be revised.

Figure 1.4: The geons cylinder and handle correspond to a Coffee cup.

While this is a fairly straightforward idea, the theory needs to be grounded not only in reason but also in empirical results. Therefore, affordance theory is often combined with the linguistic theory of image schemas.

Image Schemas: Image schemas are described as conceptual building blocks learned from the body's sensorimotor experiences. Similar to how geons capture visually perceived geometric shapes, image schemas capture spatiotemporal relationships[46] that can capture the affordances of an object. For example, above it was established that an essential property of the coffee cup is that it can 'contain' liquid. This correspond to the image schema of CONTAINMENT, which can

[44] Jean M. Mandler. Perceptual and Conceptual Processes in Infancy. *Journal of Cognition and Development*, 1(1):3–36, 2009

[45] James J. Gibson. The theory of affordances. In Robert Shaw and John Bransford, editors, *Perceiving, Acting, and Knowing: Toward an Ecological Psychology*, pages 67–82. NJ: Lawrence Erlbaum, Hillsdale, 1977

be described as the interrelationship between an inside, an outside and a border [47].

As image schemas construct the thesis' main focus, a more extensive introduction follows in Chapter 2, after the theoretical foundation has been sketched out.

To conclude the nature of concept formation: visual characteristics play a significant role in identification and categorisation of objects and concepts. However, for the conceptual processes the primary necessities appear to be affordances and conceptual building blocks such as image schemas.

One important note on both concept formation and creativity as a whole is that it is not only the identification and the categorisation that is relevant, but also the nature of generation and creation is essential. While there are many theories that (try to) explain creativity, the notion of creativity as combination of already existing knowledge has appeal. This follows the definition of creativity introduced by Mednick [1962] where associative elements were argued to be formed into new 'combinations'. In the next few sections, a few necessary theories on information transfer will be introduced before the theory of *Conceptual Blending* (CB) is given attention.

1.5 Information Transfer

For concept invention one essential part is the transfer of information. This section explores information transfer in several different domains, such as analogy and *Conceptual Metaphor Theory*.

1.5.1 Analogy

Analogy is one of the most important cognitive methods to transfer knowledge from one domain to another [48]. By comparing one thing to another with different attributes, knowledge previously not known about one of the objects can be gained simply by inferring a similarity. It is suggested that it is easier to learn and understand complicated phenomena through analogies rather than without. In everyday situations, analogies often take the form of similes: e.g. "cute as a kitten", "brave as a lion"; or metaphors such as: "the elephant in the room" or to "to kick the bucket". However, analogy is not in itself a linguistic phenomena, it exists in all stages of cognition. Hofstadter [1995] even went as far as to claim that analogy is at the core of human cognition.

The underlying mechanism of analogical thinking is that information is transferred from a rich source domain onto an information-

[46] Whether image schemas consistently are defined as spatiotemporal relationships is a controversial topic. For the current purposes, it is sufficient to limit the image schemas to spatiotemporal relationship regardless if there is more to the story.

[47] George Lakoff. *Women, Fire, and Dangerous Things. What Categories Reveal about the Mind*. University of Chicago Press, 1987

[48] Tony Veale. From Conceptual Mashups to "Bad-Ass" Blends: A Robust Computational Model of Conceptual Blending. In *Proceedings of the 2012 International Conference on Computational Creativity*, pages 1–8, Dublin, Ireland, 2012

poor target domain through identifying information structures in both domains. Simply put, an analogy comes in the following structure $a : b :: c : d$, meaning that c relates to d, in the same way as a relates to b.

One classic example of an analogy is the atom model as proposed by Rutherford. When introducing his theory of the atomic structure Rutherford used the solar system as a source domain to explain the relationship between the nucleus and the electrons by comparing the nucleus to the sun, and the electrons to the planets. On a shallow level, the analogy does its job. It provides a pupil (or someone else) the understanding that the electrons are moving in a circular motion around the nucleus. Naturally, from a physics point of view, the wrong inference is made. In the case of the atom, it is electromagnetism that ensures that the electrons keep a particular distance to the nucleus, whereas in the solar system it is gravity.

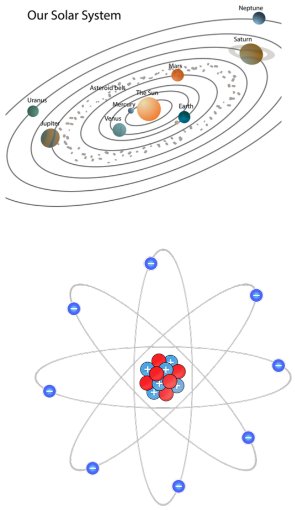

Figure 1.5: The Rutherford Atom Model: In which the relationship between the members of the atom is described using the relationship between the sun and the planets in the solar system, following the structure: Sun:Nucleus::Planet:Electron.

During the creative process, an analogy may provide an explanation to how a problem might be solved by inferring the properties of a similar relation between different conceptual spaces. The classic example aims to explain the atomic structure by using the solar system as an analogical model. To explain the different layers of electrons and the electromagnetic pull therein, the properties and the gravitation from the sun and the planets, are used.

Nagai [2009] talks about the difference between how expert and novices use analogies. Novices, who are considered to be able to apply more creativity to the problem-solving process, are much more free in how they use analogies, whereas experts use more conventional analogies. Given that experts more often adapt to routine, it is not strange that novices can more creatively apply analogies and consequently also display greater creative ability. This is also supported by neurolinguistic studies that demonstrate disjoint neural activation when exposed to conventional metaphors versus novel metaphors. For instance, the work by Schmidt et al. [2007] provides support for the idea that conventional metaphors have become part of everyday language rather than active analogical thinking.

One of the most important aspects of analogies is the search for the underlying structure in both input domains. As this is an important part of the presented research, this will be discussed in the next section.

1.5.2 The Search for Structure

An essential part of analogy is the search for common structure in the two domains. When the spatial relationship of the Rutherford atom model is transferred from the solar system to the atom, a few key concepts need to be aligned:

$$\begin{aligned} revolves\_around(planet, sun) &:: revolves\_around(electron, nucleus) \\ greater\_than(sun, planet) &:: greater\_than(nucleus, planet) \end{aligned}$$

In analogies where the underlying structure is more or less obvious, this alignment is done automatically by humans. For the Rutherford atom model the first alignment is based on Scale, namely that the sun is larger than the planets and therefore the nucleus is larger than the electrons. Additionally, the movement is transferred from how the planets Revolve_Around the sun to how the electrons are thought to Revolve_Around the nucleus.

For an artificial system, it is not obvious how to map the information between the entities in the analogy as there is no human 'commonsense' factor to play a role in determining which information transfers are more or less likely[49]. In the artificial intelligence domain, analogy engines have been introduced to automatically find and transfer the structure found in analogies. Two examples are the Structure Mapping Engine (SME) [50] and Heuristic-Driven Theory-Projection (HDPT) [51], which will be discussed further in Chapter 6.

1.5.3 Conceptual Metaphor

Conceptual metaphors, also called cognitive metaphors, are a specialised form of analogies in which a conceptual domain is used to explain the concepts of another domain [52]. Conceptual metaphors are an important part of human thinking and therefore, it is a vital part of natural language processing, machine translation and opinion mining among other application scenarios [53].

Cognitive metaphors arise out of an interconceptual mapping, that is, the association of two seemingly unrelated, distinct concepts. For instance, the conceptual metaphor ARGUMENT IS WAR is the underlying structure found in expressions such as "he *shot down* all of my arguments" and "the criticism was *right on target*". In this example, the source domain WAR allows for an analogical transfer of war-related notions such as 'shooting' and 'target' onto the expression in the target domain of ARGUMENT. The verb 'shoot' indicates that 'people', or animated agents, shoot inanimate 'objects'. In the conceptual metaphor this is violated as ARGUMENTS pose as both the implied 'bullet' and the target, as well as are abstract things. This violation is called *Selectional Restriction Violation* and has repeatedly been used to detect conceptual metaphors in text [54].

Hampe [2005] states that conceptual metaphors allow humans to map experienced, concrete structure from the sensorimotor realm

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[49] Unless the system has been provided with skills for commonsense reasoning through either knowledge representation or machine learning.

[50] Dedre Gentner. Structure mapping: A theoretical framework for analogy. *Cognitive Science*, 7(2):155–170, 1983

[51] Martin Schmidt, Ulf Krumnack, Helmar Gust, and Kai-Uwe Kühnberger. Heuristic-Driven Theory Projection: An Overview. In H. Prade and G. Richard, editors, *Computational Approaches to Analogical Reasoning: Current Trends*, volume 548 of *Computational Intelligence*, pages 163–194. Springer, 2014a

[52] George Lakoff and Mark Johnson. *Metaphors We Live By*. University of Chicago Press, 1980

[53] Ekaterina Shutova, Simone Teufel, and Anna Korhonen. Statistical metaphor processing. *Computational Linguistics*, 39(2):301–353, 2013

[54] Yorick Wilks. Making preferences more active. *Artificial Intelligence*, 11(3): 197–223, 1978

to the abstract, mental realm, thereby creating a direct connection between conceptual metaphors with embodied cognition.

One important component of conceptual metaphors is the *The Invariance Principle* which states that the structure of the source domain needs to be the structure also for the target domain [55]. Veale and Keane [1992] investigated this under what they called 'conceptual scaffolding' and focus on the spatial and conceptual attributes such as image schemas, to constitute a conceptual structure that is 'fleshed out' to give a metaphor meaning.

Conceptual metaphor theory and the search for the underlying conceptual structure is also present in creative generation of concepts. Conceptualisation is an important feature of the creative process. This is done by sorting concepts in conceptual spaces through their relationships or associations. The emergence of new concepts is hypothesised to be created through merging different conceptual spaces [56]. One recent theory that has had influence in how concepts are thought to be generated and invented is *Conceptual Blending* which builds on the cognitive mechanisms behind analogical reasoning [57]. The idea to use image schemas as a conceptual skeleton for information transfer in conceptual blending will be further discussed in Chapter 2 and further formally developed in Chapter 6.

1.6 *Conceptual Blending*

Fauconnier and Turner [1998] introduced a theory for concept invention built on the notion that creativity is a process of combining already existing knowledge into a new domain. The theory was introduced under the name 'conceptual integration' but has become famous under the term 'conceptual blending', see Figure 1.6. It has found support and encouragement for further studies from both artificial and psychological directions (e.g. Gibbs [2000], Yang et al. [2013], Grady [2001]). The theory builds on the principles of analogical reasoning, in which one domain carry information over to another domain. The difference here is that information is mapped between two input spaces that are merged into a novel space, a blend.

Combinational creativity is thought to occur when mental spaces, or conceptual spaces, merge into new spaces called 'blends'[58]. These new mentally blended spaces inherit some of the attributes of the input spaces, yet possess emergent properties, based on their unique combination, to develop their own characteristics. Following the lines of Fauconnier and Turner, Veale [2012, p. 1] explains the purpose of conceptual blending as follows:

> ... conceptual blending combines the smoothness of metaphor with the structural complexity and organizing power of analogy. We can think

[55] Mark Turner. Language is a Virus. *Poetics Today*, 13(4):725–736, 1992

[56] Joseph E. Grady. Cognitive mechanisms of conceptual integration. *Cognitive Linguistics*, 11(3-4):335–345, 2001

[57] Gilles Fauconnier and Mark Turner. Conceptual integration networks. *Cognitive Science*, 22(2):133—187, 1998

[58] In formal domains these are often called blendoids. Conceptually the terms are interchangeable, but the term blend is here used exclusively to avoid confusion.

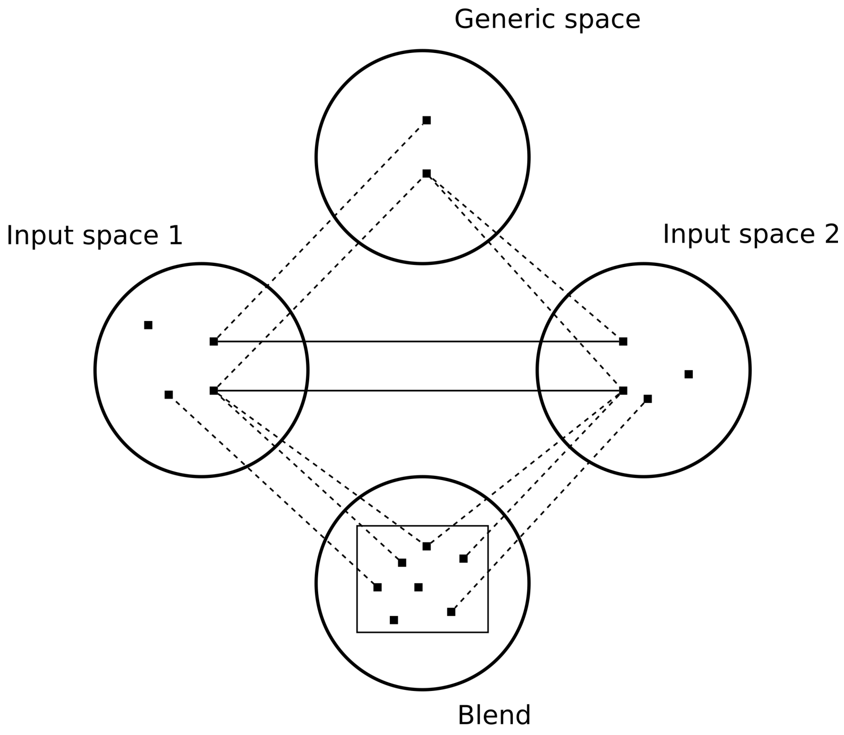

Figure 1.6: The blending process as described by Fauconnier and Turner (1998).

> of blending as a cognitive operation in which conceptual ingredients do not flow in a single direction, but are thoroughly stirred together, to create a new structure with its own emergent meanings.

The idea is that both literal and metaphoric expressions are based on multiple mental models and the internal mappings between the internal concepts therein in both target and source domains. Yang et al. [2013] use the following expression to explain the hypothesis: "That stone we saw in the natural history museum is a gem", where it is necessary to establish a mapping between the stone in the natural history museum and the gem. In a metaphoric expression such as: "He knows power is an intoxicant", the target domain 'power', gain attributes from the source domain of 'intoxicant'. In order to understand blending theory, the concept of mental space needs to be understood. Boden [2004] describes mental spaces as conceptual spaces in which different conceptual groupings have internal relations and associations to other conceptual spaces. This correlates with the blending theory's idea of mental spaces. Fauconnier and Turner [1998, p. 137] define them as "...small conceptual packets constructed as we think and talk, for purposes of local understanding and action." They are considered to be partial assemblies of elements constructed by frames and cognitive models. The vast variety of mental spaces are interconnected to each other by relations of different strength and character and both the mental spaces in themselves as well as their interrelations are modified as thought and context unfold. Abstract as it may be on a psychological level, after all it is still uncertain as to how knowledge is stored in the brain, it is easier to picture this structure in AI. As mentioned, in AI ontologies are structured in taxonomies in which all relevant information for that particular conceptual space is included through classic knowledge representation, including the concepts, the relationships and the roles that are part of the ontology.

1.6.1 *The Mechanics of Conceptual Blending*

Following the ideas behind analogical thinking, one of the central aspects of blending is the the way in which 'common structure' between the input concepts is understood to steer the creation of the new concept. The 'merging' of the input spaces is moderated by this common structure, represented as the generic space, or as it is called in formal approaches, the base ontology[59]. The common structure of the input spaces is understood to play a vital role in rendering the newly constructed concept meaningful, as it ensures that the blended space also contains the structure found in the generic space.

However, despite this influential research, within computational creativity and AI in general, relatively little effort has been devoted to fully formalise these ideas and to make them amenable to computational techniques, but see [Schorlemmer et al., 2014, Kutz et al., 2014a] for overviews.

Unlike other combination techniques, *blending* aims at creatively generating (new) concepts on the basis of input theories whose domains are thematically distinct but whose specifications share some features.

For the cognitive machinery behind conceptual blending, it is important to understand that the model for conceptual integration takes two, or possibly more, input spaces that have some kind of analogical relation to one other, see Figure 1.6. Between these two input spaces, there is a partial cross-space mapping in which different elements in each space are connected. The generic space maps onto both of the inputs, and constitute what the input layers have in common. The blended space, the 'blend', is the resulting combination given the two inputs. What is needed to understand the problem will be fused from the input layers and what needs to be excluded will simply not take part in the blend. One important feature here is that the information that is being projected into the blend is selective, meaning that unnecessary, or counterproductive, elements are left out since they do not help solve the problem. The emergent structure of these conceptual

[59] In the limit case, the shared structure might be trivial, and a concept such as 'red pencil' might be understood as a blend too, by simply imposing properties from one input space onto another.

blends also needs to be attended to. Due to the fact that conceptual spaces are mixed, new *relationships* and *compositions* can emerge and evolve. *Completion* is another of these emergent properties that bring additional structure to the blend, what might have been insufficient in one of the input spaces has more information in the blended space which might complete concepts and their interrelationship. Lastly, the emergent structure of elaboration develops the blend through imaginative mental stimulation given the current logics and principles.

This might go on indefinitely with new completion structures, as well as new logics and principles, emerging through the continuation of elaborative processes [60]. It is suggested that this view of cognition is compatible with both human psychological and computational approaches to creative associations and will, therefore, be viewed as the foundation for the cognitive machinery in the creative process.

1.6.2 The Gryphon: A Blending Example

Turner [2014] argues that human creativity came about as a blending process. One of the earliest examples of how one input space is merge with another is the estimated 35000 year old ivory sculpture the 'lion man'[61]. It is conceptual blend where a human figure has been given the head of a lion. Described as a figurative piece of art, Turner argues that it encompass not only physical features of both input spaces but also the characteristics associated with them.

In this section, a similar and entirely fictive example is used to explain the creative capacity of blending. By being a non-existing entity in the world it captures the strength of human imagination. Many mythological creatures, or 'monsters', builds on the same principles behind the 'lion man', while there are many examples of such blended creatures, for now, lets consider a gryphon. A gryphon is a fictive creature with the body and the tail of a lion and with the head and the wings of an eagle (see Figure 1.7). The blend of the two creatures does not only involve the physical attributes of the animals, but also the characteristics associated with them. The lion provides attributes such as strength and power, and the eagle precision and capacity for flight. Hence, the blended creature has the skills to master both land and sky.

The gryphon exemplifies one particular blend of the two input spaces 'lion' and 'eagle'. There are other possibilities to blend a monster based on these two concepts. For example, one could consider an 'inverted gryphon', which has the head of the lion and the body of the eagle but no wings. A third possible monster is a creature which has the shape and strength of a lion but cannot use its strength be-

[60] Gilles Fauconnier and Mark Turner. Conceptual integration networks. *Cognitive Science*, 22(2):133—187, 1998

[61] The sculpture is on display at Ulm Museum, Germany.

cause of its fragile bird-like bone structure. The last example shows that not all blends are equally successful. In order for the blend to be considered creative, the blend needs to be 'useful' [62]. Given the task of blending a monster, a successful blend is required to produce a dangerous creature – a lion with brittle bones does not meet this requirement as well as a gryphon.

The blended space preserves the information from the generic space. However, only some selected features of the input spaces are usually retained. In the gryphon example, the generic space contains the head, the body, and two limbs of a vertebrate. In the blend, the head in the generic space is mapped to the head of the lion and the head of the eagle, respectively. The same holds for the body. In contrast, the two limbs are mapped to the forelimbs of the lion and the hindlimbs (legs) of the eagle. For this reason, the gryphon has six limbs, namely two wings of the eagle, two hindlegs from the lion and two forelegs, which are inherited from both input spaces. Since the shape and features of lion legs and eagle legs are mutually exclusive (e.g. one has hair and the other has feathers), the forelegs of the gryphon cannot inherit all properties from both input spaces. Thus, a gryphon's forelegs are usually conceptualised as exemplifying either only the features of one animal or as inheriting a consistent subset of features from both input spaces.

Figure 1.7: The mythological creature gryphon, demonstrating a blend of the animals lion and eagle.

For humans conceptual blending is effortless. We are able to create new blends spontaneously and have no difficulty to understand new conceptual blends when we encounter them. This includes the selection of suitable input spaces, the identification of a relevant generic space, the identification of irrelevant features of the input spaces, the performance of the blend, and the evaluation of the usefulness of the blend. In contrast, for an automated system, each of these steps provides a significant challenge. This is demonstrated by Neuhaus et al. [2014], who aims to formally model the conceptual blending of monsters, inspired by the mythological creatures such as the gryphon[63].

1.7 *Chapter Conclusion*

This chapter introduced the foundation of the present research. Here the symbol grounding problem was introduced together with cognitive and computational issues of conceptual understanding and grounding, as well as some issues of creativity and concept invention. One of the major theories presented was the role of sensorimotor processes in conceptual development and the theory of embodied cognition. Additionally, creativity research was introduced as it provides one of the necessary stepping stones towards concept invention and computational concept generation. With this in mind, conceptual

[62] Margaret A. Boden. Computer models of creativity. *AI Magazine*, Fall 2009

[63] Visit `https://github.com/ConceptualBlending/conceptual_blending_project` for a tool that visualise these monster blends.

blending, built on the notion of analogical reasoning, was introduced as a theoretical mechanism behind concept generation through the combination of conceptual spaces.

In the next chapter, the embodied mind theory will be further discussed more specifically in the relation to the theory of image schemas as it provides a potential theoretical starting point for conceptual grounding.

2

Image Schemas: Spatiotemporal Relationships Used as Conceptual Building Blocks

The universe constantly and obediently answers to our conceptions; whether we travel fast or slow, the track is laid for us. Let us spend our lives in conceiving then.

Henry David Thoreau
Walden; or, Life in the woods,
1854

Content and Context

The previous chapter introduced the research foundation that the present research is based on. Briefly introduced was the term 'image schema' which was described as mental generalisations learned from the body's sensorimotor experiences. This chapter continues to lay the foundation by in greater detail introduce and discuss the research on image schemas as these generalisations construct the red thread of the remaining chapters.

This further introduction is done by investigating image schemas from their background in cognitive linguistics as well presenting some empirical support that has been offered from research in developmental psychology. As image schemas are approached in the light of solving the symbol grounding problem for artificial intelligence and computational concept invention, the chapter will focus on introducing some of the requirements and problems that will be dealt with in the upcoming chapters.

The chapter includes:

- History of image schemas
- Defining image schemas
- Image schemas in psychology and linguistics
- Structuring image schemas
- Image schemas in narratives

2.1 Image Schemas

2.1.1 Embodied Cognition and Image Schemas

Embodied cognition offers a concrete method on how to theoretically view the symbol grounding problem. The direct link between embodied experiences and the representations in the mind is appealing not only from a cognitive perspective but from an artificial intelligence perspective as well.

However, embodied cognition in itself does not offer any solutions to how the embodied experiences are mentally represented. Instead, both classic mental representations, as well as meaning being stored in the neural activation of the sensorimotor cortex, are offered as possibilities for how conceptual information is preserved [1]. One theory that aims to bridge this gap of information of how the embodied experience mentally manifest is the theory of image schemas.

The term Image schema[2] was simultaneously, but disjointly, introduced by Lakoff [1987] and Johnson [1987] in the late 1980s. However, the philosophy behind the theory dates back (if not earlier) to the German philosopher Kant [1781] who termed the notion of 'schema': a non-empirical concept formed from sensorimotor experiences.

Since its introduction, the theory has become an important notion to ground higher cognitive phenomena, such as language and reasoning, in the low-level sensations acquired from embodied experiences.

Image schemas are said to be the conceptual building blocks that are derived from the embodied experience in the early infancy [3]. They are preverbal and while language and reasoning build from them, they are not in themselves learned from language. While there are discussions on which concepts should be included in the term image schema, a common restriction is to describe them as the generic spatiotemporal relationships [4] learned from the repeated interaction and perception with and of the environment and the objects therein. The first pertinent distinction is that image schemas can be both static and dynamic [5].

While there is currently no consensus on the number of image schemas or which notions are image-schematic to begin with, some common examples are CONTAINMENT, SUPPORT and LINK (see Figure 2.1). Despite working on the topic of introducing novel image-schematic concepts and how to structure them, no concrete stand on which image schemas that should be counted into a canon of image schemas is made. Instead, conventions from the literature are used where already introduced image schemas and their primitives are written with small caps, spatial and conceptual primitives that are still up for general agreement are written in simple lower case. The only exception where novel image schemas are written with small caps are those that can be provided with empirical support.

[1] Lawrence Shapiro. *Embodied Cognition*. New problems of philosophy. Routledge, London and New York, 2011

[2] In plural, image schemas or image schemata after the Greek plural form of 'schema'.

[3] Jean M. Mandler. *The Foundations of Mind: Origins of Conceptual Thought: Origins of Conceptual Though*. Oxford University Press, New York, 2004

[4] Image schemas are by definition multimodal, extracted from all sensorimotor inputs and it might be limiting to speak of them as spatiotemporal relationships. However, for the current purposes, this restriction will be proven useful.

[5] Ming-yu Tseng. Exploring image schemas as a critical concept : Toward a critical-cognitive linguistic account of image-schematic interactions. *Journal of literary semantics*, 36:135–157, 2007

2.1.2 A Brief History of Image Schemas

As mentioned, the theory was introduced in its current form by Lakoff [1987] and Johnson [1987] but the ideas date back in history.

Most prominent in the history of philosophy and epistemology is how Kant introduced the notion of a 'schema'. It denotes a mental construct, or a concept, that while non-empirical in itself is based on the sensational experiences. The Kantian schema laid the foundation for theories in which the embodied experience was related to mental constructs.

However, the Kantian 'schema' only takes half of the image schemas into account. The second part 'image', has led to image schemas often being confused to be abstract visual representations, partly due to the (somewhat unfortunate) terminology and partly due to the proportionally high representation of vision in our perception. However, as Oakley [2010, p. 215] points out "...image schemas are neither images nor schemas in the familiar sense of each term as used in philosophy, cognitive psychology or anthropology". Instead, in the same way that embodied experiences are multimodal, so are image schemas. For instance, auditory experiences appear more abstract and have therefore a distinct logic and different expressions than the ones found solely in vision and more concrete situations. As an example, a piece of music may be 'shared' between an audience in a completely different way than a piece of cake can be. The way we abstract away from auditory experiences might, thus, differ greatly from the corresponding process for visually perceived experiences and similar for other sensory modalities and/or combinations thereof. Hence, it is important to make the distinction that image schemas are not simply abstract visual representations but are of a genuinely different nature and quality. The image schemas are instead mental patterns, capturing the most general abstraction of experience and are consequently not 'images' as such. Instead, the term 'image' was introduced due to inspiration from cognitive linguistics, more precisely the work by Talmy [1988].

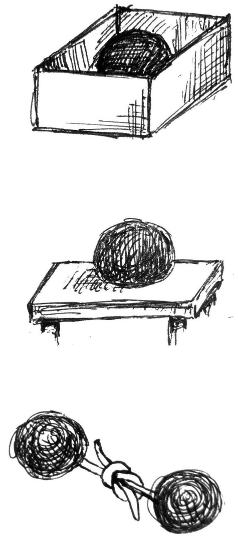

Figure 2.1: Image Schema Examples. From top: Containment, Support and Link.

Talmy [1983] made observations that spatial relations seem to have different meanings in language. His research highlights how spatial relations can be decomposed into conceptual primitives ('images') that recur across languages. Some of these images were Containment and Source_Path_Goal. He specifically pointed out that these spatial images came in three different categories: *orientational* (e.g. Above), *topological* (e.g. Contact), and *force-dynamic* (e.g. Support) [6]. Static image schemas are naturally more straightforward to define than dynamic image schemas. However, image schemas are spatio*temporal*, meaning that their dynamic aspects also need to

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[6] Leonard Talmy. Force dynamics in language and cognition. *Cognitive science*, 12(1):49–100, 1988; and George Lakoff and Raphael Núñez. *Where Mathematics Comes From: How the Embodied Mind Brings Mathematics into Being*. Basic Books, New York, 2000

be taken into account. For instance, consider how the image schema Containment can either describe the situation in which a cup already contains coffee, but also the situation in which the coffee is poured from a source: a kettle, to a goal: a cup, defined as an In and Out schema.

Inspired by the research of Kant [1781] and Talmy [1988, 1983], Lakoff [1987] introduced the term 'image schemas' to express the spatial relationships found in language based on the embodied experiences.

While Talmy was the one to introduce these spatial concepts, other researchers have focused on conceptual primes and semantic primitives (e.g. Wierzbicka [1996], Mandler [1992]).

While Lakoff and Johnson were more or less working simultaneously on the introduction of image schema, Johnson was the one to focus on the embodied properties of image schemas [7].

As the progression of cognitive science took a more concrete nature through the increased influence of neuroscience and the growing knowledge of the functions of the brain, the view of connectionism also started to influence the view of image schema research.

One of the most influential research contributions on neural networks and connectionism in terms of semantic primes, is the work by Regier [1996] who developed a substantial network to model the brain and cognitive phenomena such as image schemas. This work was supported from neuroscientific research in which Feldman and Narayanan [2004] continued to build neural models of image schemas.

Since a few decades, the image schema research has taken a different direction as the prime research goal is no longer exclusively to model human cognition, but also to simulate it in a formal domain. Geographical information science (GIScience)[8], artificial intelligence, computational creativity and a range of other computational areas has taken a liking to the idea of using image schemas as a form of design patterns when constructing models of narratives and ontologies [9].

2.2 *Defining 'Image Schema'*

The interdisciplinary history of image schema research hints at one of the major obstacles for further research, namely that as of yet there exists no agreed upon terminology. The term 'image schema' is poorly defined with definitions that vary between research disciplines, individual scientists as well as methodologies.

Today image schemas are studied in several fields of research including, amongst others, neuroscience (e.g. Rohrer [2005]), devel-

[7] Mark Johnson. *The Body in the Mind: The Bodily Basis of Meaning, Imagination, and Reason*. University of Chicago Press, 1987

[8] GIScience is the scientific discipline investigating representations of geographic concepts and relations [Kresse and Danko, 2012].

[9] As in design ontology patterns [Gangemi and Presutti, 2009].

opmental psychology (e.g. Mandler [1992], Watters [1996]), cognitive linguistics (e.g. Hampe and Grady [2005], Tseng [2007]) and formal knowledge representation and artificial intelligence (e.g. Frank and Raubal [1999], Kuhn [2007], St. Amant et al. [2006], Bennett and Cialone [2014]). Different disciplines have different focus and different scientific backgrounds. Therefore, it follows as no surprise that the terminology on image schemas has been left somewhat unclear. An additional reason for this problem is the disputed relationship between socio-cultural aspects and the neurobiology of embodied cognition [10] which has further complicated the attempts to make a concrete definition of image schemas.

When Johnson [1987, p. xiv] introduced image schemas he described them using the following words:

> An image schema is a recurring, dynamic pattern of our perceptual interactions and motor programs that gives coherence and structure to our experience.

The linguist Oakley [2010, p. 215] defines instead an image schema as:

> ...a condensed re-description of perceptual experience for the purpose of mapping spatial structure onto conceptual structure.

Another definition, paraphrased from Hampe [2005], is that image schemas are "...directly meaningful ("experiential"/"embodied"), pre-conceptual structures, which arise from or are grounded in human recurrent bodily movements through space, perceptual interactions and ways of manipulating objects". Further, she points out that it follows that they are highly schematic *Gestalts*[11] that capture the structural contours of sensory-motor experience, integrating information from multiple modalities and exist as continuous and analogue patterns beneath conscious awareness, prior to and independently of other concepts; and are both internally structured and highly flexible.

While research in cognitive linguistics has several interpretations on what it means to have linguistic primitives, the formal domain of image schema research has taken a slightly more straightforward view. As a representative for this research group, Kuhn [2007] defines image schemas as "...the pre-linguistic structures of object relations in time and space". This is a common focus in formal image schema research as by defining image schemas as spatiotemporal relationships, research on *Qualitative Spatial Reasoning* (QSR)[12] as well as Geographic Information Science research offer a good research foundation.

One problem with agreeing on a definition of image schemas is that the current definitions do not provide an individuation criterion between image schemas. In turn, this leads to two other problems.

[10] Beate Hampe. Image schemas in cognitive linguistics: Introduction. In Beate Hampe and Joseph E Grady, editors, *From perception to meaning: Image schemas in cognitive linguistics*, pages 1–14. Walter de Gruyter, 2005

[11] Gestalts in the sense of Gestalt theory and Gestalt laws.

[12] QSR is an area of AI that studies spatiotemporal reasoning that approximates human commonsense understanding of space [Ligozat, 2011].

The first, here called *The Structure Problem*, captures that it is hard to evaluate which spatiotemporal constructs qualify to be described as image schemas as many similar conceptual structures are spoken of interchangeably under one image schema. The second problem, here called *The Categorisation Problem*, captures that it is difficult to determine which image schema a particular construct belongs to. As image schemas are abstract concepts it is likely that in the human brain, the nature and borders between different schemas may be flexible and up for the context to define. However, for computer science, these two problems are essential to solve before any formal representation of image schemas can be successful. Both of these two problems will be discussed further in the two upcoming sections and Chapter 3 and Chapter 5 will present suggestions on how these two problems can be overcome in formal settings.

2.2.1 The Structure Problem

It is uncertain when spatiotemporal constructions should qualify as image schemas. One of the criteria for a mental construct to be considered an image schema is that they need to follow the general rules of *Gestalt Theory*[13] [14]. For example, it is not possible to remove the 'border' from the CONTAINMENT image schema, nor is it possible to speak of solely 'an inside' without at least implicitly considering 'a border' and 'an outside' as well. However, even with this strict definition Bennett and Cialone [2014] could identify no less than eight different kinds of static CONTAINMENT through a corpus study. This was done exclusively for static forms of CONTAINMENT and if transformations and movement IN and OUT are included, then the 'number' of CONTAINMENT schemas would increase even further. This indicates that each image schemas cannot be described as an isolated theory that can easily be defined, but that they are complex webs of associated notions and transformations. Other support for image schema networks stems from the idea to structure image schemas as conceptual clusters [15].

However, these image schema clusters can be shown to vary in complexity as well, ranging from conceptual primitives to image schemas and increasingly complex mental manifestations. This is supported with how accumulating experience a child has with its environment, the image schemas become increasingly fine-tuned and more specialised for the context [16].

These conceptual components are a research field in its own, but they are often included under image schema research as well. Here, spatial or temporal components construct more complex image schemas. Some influences are Mandler's [1992] spatial primitives,

[13] Gestalt psychology aims to understand the laws behind the ability to make sense and acquire meaningful perceptions in a seemingly chaotic world. The main hypothesis proposes that the mind has the capacity to 'self-organise' its perceptions [Koffka, 1935].

[14] George Lakoff and Raphael Núñez. *Where Mathematics Comes From: How the Embodied Mind Brings Mathematics into Being*. Basic Books, New York, 2000

[15] Francisco Santibáñez. The object image-schema and other dependent schemas. *Atlantis*, 24(2):183–201, 2002

[16] Tim Rohrer. Image schemata in the brain. In Beate Hampe and Joseph E Grady, editors, *From perception to meaning: Image schemas in cognitive linguistics*, volume 29 of *Cognitive Linguistics Research*, pages 165–196. Walter de Gruyter, 2005

Talmy's [2005] conceptual primitives and Wierzbicka's [1996] semantic primes.

One way to solve this problem is to divide the image-schematic components into a hierarchy based on how specific and/or complex they are. Mandler and Cánovas [2014] divide image schemas into three levels:

1. *Spatial primitives:* The first building blocks that allow us to understand what we perceive: PATH, CONTAINMENT, THING, CONTACT, etc.
2. *Image schemas:* Representations of simple spatial events using the primitives: PATH OF THING, THING INTO CONTAINER, etc.
3. *Schematic integrations:* The first conceptual representations to include non-spatial elements, by projecting feelings or non-spatial perceptions to blends structured by image schemas.

This means that the literature on image schemas mentions a plenitude of different conceptual structures on different levels of specificity that still are referred to as belonging to one particular image schema. This is a problem not only for formal investigations of image schemas, but also for linguistic and psychological investigation. The structural problem will be addressed in the upcoming chapter.

2.2.2 *The Categorisation Problem*

Image schemas are not only hard to categorise and structure within their own 'image schema', but also difficult as more complex image schemas often appear as combinations of simpler image schemas [17]. As image schemas often share conceptual primitives and have similar characteristics it is difficult to determine which image schema a particular structure belongs to. This problem is here introduced as the categorisation problem.

For example, it is clear that apples can be SUPPORTed by plates, likewise, they can be placed 'inside' (CONTAINMENT) bowls. But in the case of an overflowing fruit bowl, in which the apple, by perception, is 'outside' of the bowl it is still possible to say that the apple is *in* the fruit bowl.

This problem is amplified further by the heterogeneous way image schemas seem to manifest. For instance, image schemas by their nature undergo spatiotemporal transformations [18]. This means that the image schema itself is not an isolated notion but instead a dynamic one. From a formal point of view it might be beneficial (i.e. simpler) to focus on static image schemas alone. However, this comprises a major simplification and is not cognitively adequate, as image schemas also essentially model change over time. The notion of CONTAINMENT is, in its most basic form, defined as the relationship

[17] Todd Oakley. Image schema. In Dirk Geeraerts and Hubert Cuyckens, editors, *The Oxford Handbook of Cognitive Linguistics*, pages 214–235. Oxford University Press, Oxford, 2010

[18] Todd Oakley. Image schema. In Dirk Geeraerts and Hubert Cuyckens, editors, *The Oxford Handbook of Cognitive Linguistics*, pages 214–235. Oxford University Press, Oxford, 2010

of an inside, an outside, and a border [19]. Yet, looking at cognitive development, it is not this relationship that the understanding of CONTAINMENT seems to stem from. Instead, it appears as though the most important grounds for image schema development lie in the change over time, here the movement IN and OUT of a container [20]. Many scenarios involving movement, most commonly associated with the image schema SOURCE_PATH_GOAL, can be combined with other image schemas. The movement into a container (above THING INTO CONTAINER), or the IN schema, could be described as the combination of both SOURCE_PATH_GOAL and CONTAINMENT.

The categorisation problem concerns how to determine which image schema a particular image-schematic concept belongs to. This problem will be addressed in Chapter 3 and Chapter 5.

2.3 *Common Image Schemas and Their Definitions*

Despite the current lack of a clear-cut image schema repository, the present research will use of a set of commonly investigated image schemas and will mention, in relation to previous work or the work conducted, a full range of other image-schematic components. This section will present and describe the relevant image schemas mentioned in this volume. This list is by no means exclusive nor exhaustive.

CONTAINMENT*:* Is one of the most studied image schemas [21]. It denotes the relationship between an inside and outside and the border in between. From a dynamic aspect, it also contains image-schematic components such as IN and OUT.

SOURCE_PATH_GOAL*:* Concerns movement from a source to a goal. It contains spatial primitives such as a path and a trajectory.

CYCLE*:* The returning pattern, such as the daily cycle.

CONTACT*:* Physical (or sometimes abstract) contact between two objects.

SUPPORT*:* Denotes a relationship between two objects in which one object offers physical (or abstract) support to the other.

LINK*:* An enforced connection between objects or regions, where transitivity ensure that the linked object reacts to the stimuli of the other object.

VERTICALITY*:* Relative position such as High/Low and Above/Below are part of the image schema, likewise vertical orientation, also dynamical movement UP-DOWN is part of the image schema.

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[19] Mark Johnson. *The Body in the Mind: The Bodily Basis of Meaning, Imagination, and Reason.* University of Chicago Press, 1987

[20] Jean M. Mandler and Cristóbal Pagán Cánovas. On defining image schemas. *Language and Cognition*, 6(4):510–532, May 2014

[21] Ernest Davis, Gary Marcus, and Noah Frazier-Logue. Commonsense reasoning about containers using radically incomplete information. *Artificial Intelligence*, 248:46–84, 2017

Scaling*:* Deals with how object size range from small to large, as well as the dynamic transformation of Growing/Shrinking.

Near_Far*:* The concept of distance. Associated to Scaling as children are believed to learn the concept from how objects grow visually larger when they move closer and vice versa.

Blockage*:* A complex image schema capturing the understanding that movement can be hindered.

Caused_Movement*:* A complex image schema in which movement of one object is transferred to another.

Self_Movement*:* A complex image schema in which movement can start without external stimuli. The image schema is tightly connected to the notion of agency.

Attraction*:* The force relationship that ensures that one object is drawn to another.

2.4 *Reasoning with Image Schemas*

Cognitive support for image schemas comes from how they offer infants conceptual grounds to make predictions about their surroundings [22,23]. Indeed, work in linguistics (e.g. Dodge and Lakoff [2005]) and psychology (e.g. Mandler and Cánovas [2014]) reveal image-schematic involvement in reasoning and language development. In developmental psychology, the image schema demonstrates how key concepts are transferred through analogical reasoning and conceptual metaphors [24]. For instance, if the image schema Containment has been learned by exposure to everyday events such as 'embraces', 'entering/exiting' houses, and 'eating', the understanding that 'objects can be within other objects' can be transferred to other situations. Provided the infant has sufficient knowledge about the involved objects/domain elements, it can use Containment to predict that water will remain in a glass when it is poured therein, that people can be inside cars, and so on. Likewise, if an infant been exposed to enough set dining tables, it might have understood that 'tables Support plates'. In combination with experiences such as 'laying on the ground' and 'sitting on a swing' the child learns to generalise these experiences under the image schema Support. This generalisation can consequently be transferred to other situations in which the object relation is similar to that it has already observed and categorised. Thus, through analogical reasoning the infant can infer that 'desks will Support books'. The corresponding knowledge

[22] Jean M. Mandler. *The Foundations of Mind: Origins of Conceptual Thought: Origins of Conceptual Though*. Oxford University Press, New York, 2004

[23] Raymond W. Gibbs and Herbert L. Colston. The cognitive psychological reality of image schemas and their transformation. *Cognitive Linguistics*, 6: 347–378, 1995

[24] Zoltán Kövecses. *Metaphor: A Practical Introduction*. Oxford University Press, Oxford, USA, 2010

transfer becomes an essential part of cognition and can, as the cognitive development reaches increasingly more abstract understanding in early adolescence [25], provide a foundation for abstract thought as well.

One important distinction, made by Lakoff and Núñez [2000], is between the 'expected movement' and the 'actual' movement. For example, if the infant has learned the image schema of Support it may still not comprehend that a water surface follows a different set of physical laws than the wooden surface of a dining table. This is believed to be the foundation for how new image-schematic differentiations and structures are acquired. While a rubber duck will float on the water surface, a stone will not. The surprise of the unfulfilled expectations allows the child to restructure its expectations for future scenarios.

2.4.1 *Image Schemas as Information Skeletons in Conceptual Metaphors*

This analogical transfer of information is proposed to be present also as language is developed, in particular when abstract concepts are concerned. In the previous chapter, conceptual metaphor theory was discussed in how metaphors often are based on underlying conceptual structures such as UP is GOOD/DOWN is BAD. Stripping these structures down often results in a skeleton of image schemas (see Figure 2.2). In the previous examples, Verticality constructs this skeleton. This is demonstrated in how image schemas sometimes constitute the transferred information in conceptual metaphors [26]. For example, we can 'offer Support to a friend in need' and '*put in* a good word for someone', both expressions that offer some evidence. Pauwels [1995] even went so far to claim that any abstract use of the word 'put' requires the understanding of Containment. Containment is an important image schema in the conceptualisation of mental or affective states: 'one can *get out of* a depression' and 'people *fall in* love'. Likewise, the Verticality schema is often used to explain the emotional scale between 'happiness/sadness' as well as social status. For instance, consider the expressions 'To *fall* from grace', 'to be *high* in spirit', 'to feel *down*', and '*to climb* the career ladder'.

The involved verb/preposition apply the idea of Verticality to abstract domains which follows the common metaphoric pattern that 'up' is good and 'down' is bad. Abstract examples of the Path-following schema are 'the flow of money', 'life is a journey' and 'to walk the line'.

These examples of how image schemas are used in language to explain abstract notions are still rooted in the direct expression asso-

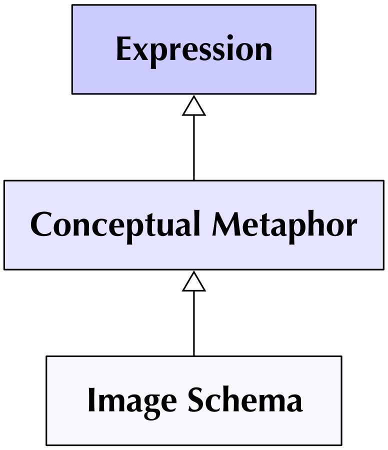

Figure 2.2: The hierarchy of the conceptual structure in metaphors.

[25] Jean Piaget. *The origins of intelligence in children*. NY: International University Press, New York, 1952. Translated by Margaret Cook

[26] Zoltán Kövecses. *Metaphor: A Practical Introduction*. Oxford University Press, Oxford, USA, 2010

ciated with image schemas. Here, Containment is associated with verbs/prepositions, such as in, out, through, enclosed etc., and Path-following is associated with words such as movement, process, going, to-from etc. (this phenomenon is used in Chapter 8 to automatically identify image schemas in natural language).

This spatiotemporal information transfer can also be found in non-linguistic domains, such as the abstract concepts in the arts and music (e.g. Antović [2009], Antović et al. [2013], Dancygier and Vandelanotte [2017], development of mathematical understanding (e.g. Lakoff and Núñez [2000], Vandervert [2017]), and time conceptualisation (e.g. Boroditsky [2000]). Time is particularly interesting as it often is viewed as a spatial Path or region on which events are perceived as 'physical' Objects [27]. For example, expressions such as 'we meet *on* Thursday', map information from a concrete situation such as 'a book on a table' to the abstract process and time period.

There exists one more possible level of skeletal information abstraction by using image schemas. Namely, how image schemas can be seen as direct 'building blocks' for the conceptualisation of concepts. While some words and concepts cannot (entirely) be described using only image schemas, as other characteristics and object properties might be equally important, some concepts can be. A cup can be described as a container (Containment), a chair as an object providing Support, building on the idea of affordances. More abstract concepts such as 'Transportation' can also be broken down into image schemas. Transportation being a combination of Path and either Support or Containment (this use of image schemas is empirically investigated in Chapter 7). This kind of combination is parallel in its constellation, but there are also combinations of image schemas that alter the nature of the image schema. For example, a common conceptualisation of the concept 'marriage' implies a Linked_Path (image schema combinations are investigated further in Chapter 5). Here the components of the image schemas are merged rather than sequentially added. This illustrates the Gestalt structure of image schemas, meaning that no component can be removed or added without changing the logics of the image schemas [28].

2.4.2 *Combining Image Schemas*

It is an important aspect of image schemas that they can be combined with one another [29,30,31,32]. This can be done in at least three ways (these will be further discussed and formally approached in Chapter 5). First, the image schemas can *merge* with one another to alter the characteristics of the image schema involved. For instance, the image schema Path can easily merge with the image schema Link,

[27] Michiel Van Lambalgen and Fritz Hamm. *The Proper Treatment of Events*. Explorations in Semantics. Wiley, 2005

[28] George Lakoff and Raphael Núñez. *Where Mathematics Comes From: How the Embodied Mind Brings Mathematics into Being*. Basic Books, New York, 2000

[29] Werner Kuhn. An Image-Schematic Account of Spatial Categories. In Stephan Winter, Matt Duckham, Lars Kulik, and Ben Kuipers, editors, *Spatial Information Theory*, volume 4736 of *Lecture Notes in Computer Science*, pages 152–168. Springer, 2007

[30] Lisa Walton and Michael Worboys. An algebraic approach to image schemas for geographic space. In *Proceedings of the 9th International Conference on Spatial Information Theory (COSIT)*, pages 357–370, France, 2009

[31] Jean M. Mandler and Cristóbal Pagán Cánovas. On defining image schemas. *Language and Cognition*, 6(4):510–532, May 2014

[32] Todd Oakley. Image schema. In Dirk Geeraerts and Hubert Cuyckens, editors, *The Oxford Handbook of Cognitive Linguistics*, pages 214–235. Oxford University Press, Oxford, 2010

leading to the more complex image-schematic concept Linked_Path. As Path illustrates a movement through space, and Link illustrates the causal relationship between two (or more) objects, a Linked_Path represents joint movement on two paths; e.g. a truck and trailer moving along a highway, or the joint movement of two separate magnets. An example is the conceptualisation of the concept 'marriage', where two individuals go through life together [33]. Alternatively, marriage may also be conceptualised as Containment. This is reflected by metaphors like 'marriage is a prison', 'marriage is a safe harbour', and 'open marriage'. Depending on whether one chooses Containment or Linked_Path as a base for the conceptualisation of marriage, a different vocabulary and different metaphors are supported.

Second, as mentioned, Path can be combined with Support (or Containment) and result in the concept 'transportation' [34]. This is a combination that behaves as a *collection* as each image-schematic structure remains conceptually intact.

Finally, image schemas can be combined *sequentially* to form a more complex image-schematic notions. A metaphorical example is the idiom 'to hit the wall'. In most contexts, this does not mean to physically crash into a wall, but instead implies a mental breakdown often caused by long-term stress. This idiom captures the image schema of Blockage. It is clear that Blockage is not an atomic image schema but rather a sequential combination of several ones. Breaking it down, there are two Objects, one Source_Path_Goal and at least one time point when the two objects are in Contact. Connecting it to the idiom it is possible to see how a physical Path is mapped to the time and processes that precede the moment of the 'crash'. This line of reasoning is properly dealt with in Chapter 5.

2.4.3 *Image Schema Profiles*

Taking one step further to discuss how image schemas and their combinations are used in conceptualisations it can be demonstrated how early during cognitive development children can reason and conceptualise simple events [35].

Oakley [2010] describes how *Image Schema Profiles* are a collection of image schemas that together describe the conceptualisation of particular events and concepts. For instance, in complex conceptualisations involving many aspects such as 'going to the library', the scenario can be described using a series of image schemas, in this particular case:

- Source_Path_Goal
- Containment

[33] Jean M. Mandler. *The Foundations of Mind: Origins of Conceptual Thought: Origins of Conceptual Though*. Oxford University Press, New York, 2004

[34] Werner Kuhn. An Image-Schematic Account of Spatial Categories. In Stephan Winter, Matt Duckham, Lars Kulik, and Ben Kuipers, editors, *Spatial Information Theory*, volume 4736 of *Lecture Notes in Computer Science*, pages 152–168. Springer, 2007

[35] David Sobel and Natasha Kirkham. Blickets and babies: the development of causal reasoning in toddlers and infants. *Developmental Psychology*, 42(6): 1103–1115, 2006

- Collection
- Part_Whole
- Transfer
- Iteration

Through conceptualisation of events over time, these image schemas go through 'image schema transformations'. These are the dynamic notions of particular sensorimotor experiences that translate into the complex layers of image schemas. For instance, an infant learns that objects Scale from small to large, and vice versa, as objects move closer/further away. This means that from the perspective of image-schematic transformations the Near_Far image schema has conceptual overlap to the Scale image schema.

Image schema profiles are the 'event' parallel to how image schemas can be seen as building blocks for concepts. Chapter 5 will be looking at how image schemas construct the conceptual skeleton for also larger scale conceptualisations and more complex image schemas.

2.5 *Image Schemas in Language and Conceptualisations*

Image schemas were originally introduced as a means to explain linguistic phenomena from the perspective of the embodied mind. This section aims to introduce some of the relevant work performed in the cognitive linguistics on image-schematic structures.

2.5.1 *Cross-lingual Investigations*

One of the more common methods to study image schemas is by comparing their manifestation in different languages. As image schemas stem from the body's sensorimotor experiences it should follow that they are language independent. However, as language expression is a socio-cultural product, certain fine-tunings might exist. This is supported by research that shows how the conceptual system underlying image schemas may change in individual languages, but that the fundamental conceptual notions vary marginally cross-linguistically [36]. One example is how different degrees of specificity of Containment can be expressed in different languages. For instance, Korean differentiate between tight or loose Containment, a distinction not present in English [37]. Likewise, regarding Source_-Path_Goal and the linguistic identification of motion information, Papafragou et al. [2006] found that English speakers are more likely to linguistically encode manner of motion information than Greek speakers. This was generalized to cross-linguistic asymmetries and the authors could differentiate between *Manner languages* (e.g. Ger-

[36] Jean M. Mandler and Cristóbal Pagán Cánovas. On defining image schemas. *Language and Cognition*, 6(4):510–532, May 2014

[37] Laraine McDonough, Soonja Choi, and Jean M Mandler. Understanding spatial relations: Flexible infants, lexical adults. *Cognitive Psychology*, 46(3): 229–259, 5 2003

man, Russian, Chinese) from PATH *languages* (e.g. French, Spanish, Turkish). Since the SOURCE_PATH_GOAL schema is not only spatial but also temporal, time as a concept has been frequently considered as an important aspect. Regarding image-schematic conceptualisation of time, the classic western view is that of a PATH, however, Fuhrman et al. [2011] found that in Chinese a vertical representation of time is preferred over the English horizontal one. Additionally, Núñez and Sweetser [2006] found that the spatial construal of time can vary in the sense of whether the future is depicted as in front or behind the speaker.

In the experiment by Lakusta and Landau [2005] participants were asked to verbalize visualizations, such as change of possessions necessitating a transaction between agents. The purpose was to identify the linguistic encoding of different specificities of PATHS in English speaking children and adults. Their findings showed that an asymmetrically higher frequency of PATH_GOALS over SOURCE_PATHS, heavily implying that the SOURCE_PATH_GOAL schema has multiple members of different levels of detail and information.

Also looking at the different components of SOURCE_PATH_GOAL is the work by Watters [1996] who looked at *Tepehua*, an eastern Mexican language, where suffixes and prefixes alter the image-schematic character of verbs. For instance, by these additions, spatial primitives such as a GOAL would be added to the SOURCE_PATH_GOAL schema.

2.5.2 *Particular Image Schema Investigations*

Ekberg [1995] performed a study aiming to identify the different usages of the image schema VERTICALITY by looking at both English and Swedish expressions. Her work shed light on that in language, VERTICALITY and its connecting prepositions are used in five different scenarios that not always include the vertical axis. Instead, VERTICALITY is also used to express things like horizontality (as in 'walking up the corridor') and goals (as in 'reach up to the counter'). She makes a strong claim that image schema characteristics pervade the meaning structure even in the most common place grammatical items.

Also investigating the relationship between VERTICALITY and horizontality is the work by Serra-Borneto [1996]. By looking at conceptually perceptual and non-perceptual occurrences of the words 'liegen' and 'stehen'[38] he could motivate the idea that image schema theory provides a cognitive explanation for the subtle meaning shifts. Gibbs et al. [1994] also looked at the word 'stand' by focusing on polysemy and found empirical support for the notion that image

[38] German for 'laying' and 'standing'.

schemas organise experience and as such organise semantic structure.

A study performed on the concept of 'straight' was done by Cienki [1998]. While 'straight' had not been introduced as an image schema of its own right, Cienki demonstrated by comparison to the VERTICALITY schema, how 'straight' could be detected as a recurrent pattern of action, perception and conceptualisation. In natural language 'straight' is often used when talking about morals and ethics as in expression such as "give it to me *straight*". It could be argued that straight should be described as a visual characteristic rather than an image-schematic one (much like colours are used to explain emotional states 'to see *red*' as a description of anger, 'to have the *blues*' when feeling sad or 'to be *green* of envy'). However, the 'straight' is not solely a phenomenon in Indo-European discourse, but can also be seen to have similar conceptual implications in the domain of ethics in other languages such as Hungarian and Japanese.

Rhee [2002] looked at the word 'against' to distinguish four processes for semantic change: metaphor, generalisation, subjectification, frame-to-focus variation. His main argument follows that semantic change involved image schemas and their transformation, as despite meaning may change during these transformations, the image-schematic structure does not. The same claim was made by Verspoor [1995]. However, this was counter-argued for by Matsumoto [1995], as Japanese does display a change in image-schematic structures as well.

2.5.3 Multimodal Image Schemas and Synaesthesia

Wagner et al. [1981] performed a synaesthesia[39] experiment where they paired perceptual events that share no physical features, e.g. visual drawings and sound sequences. For example, they had children look at dotted lines together with either pulsing sound or consistent sound and found that the image-schematic structure was an important aspect for connecting the different aspects.

Antović [2009] tested the conceptual metaphor theory mentioned in Chapter 1, by empirically investigating the conceptualisation of basic musical relations. Their results indicated that children to a large extent conceptualised music by using metaphors based on image schemas such as VERTICALITY or SCALING to explain for instance pitches. In a second study, Antović et al. [2013] addressed the perceptual basis for developing abstract concepts. The study further supported the preference for visuospatial descriptions for music conceptualisations.

[39] Synaesthesia is the perceptual phenomenon in which one sensory stimulus elicit involuntary reactions in another sensory or cognitive pathway.

2.6 Chapter Conclusion

This chapter gave a thorough introduction to the theory of image schemas. The theory originates from cognitive linguistics as a means to explain the extent of spatial language in conceptual metaphors and abstract language. Here image schemas were discussed as the conceptual building blocks generalised from the sensorimotor experiences in early infancy. This means that they provide a theoretical stepping stone between embodied experiences and mental representations. In this role, they provide an information skeleton that can be used to structure conceptual information and be used as information transfer in analogical reasoning and conceptual blending.

Due to the interdisciplinary research topic, image schemas are hard to define and two major problems exist concerning building a repository of image schemas: the structure problem, which deals with identifying the borders for what conceptual structures should be considered image-schematic and how they can be organised; and the categorisation problem, which deals with the difficulty to determine which image-schematic structure belongs to which image schema. This is the major topic for the upcoming Chapter 3 in which image schemas are suggested to be ordered in a hierarchy based on family resemblance.

Additionally, the problem of how image schemas can be combined with one another to generate image schema profiles, the underlying conceptualisation of concepts and events was discussed. This is the primary topic for Chapter 5 and the ideas that structure Chapter 7.

In the following chapters, the work on image schemas will be transposed into a formal domain with the intention of using the conceptual information present in image schemas as a cognitive inspiration for natural language understanding and concept invention in artificial intelligence.

3

Formal Structure: Image Schemas as Families of Theories

Similarity is stasis; difference is motion. And if the two happen to exist in dynamic equilibrium everything is right in the world.

Youngme Moon
Different, 2010

Content and Context

The previous chapters introduced the framework for computational concept invention while focusing on the theory of image schemas and how this could be used as inspiration for potential formal approaches. During the introduction of image schemas, the structure problem and the categorisation problem for image schemas were introduced and explained. They capture the problems of determining which conceptual structures are image-schematic respective which structures belong to which image schema. This chapter addresses these issues by introducing a method for how to structure image-schematic notions. The categorisation problem is approached by allowing notions of similar structure to be part of an image-schematic family that group together similar concepts rather than having strict definitions of a particular image schema. Simultaneously, the structure problem is approached by ordering this family into a hierarchy where simpler concepts are made increasingly more complex by the addition of conceptual and spatial primitives. These methods solve, to some degree, the issues regarding defining and classifying image-schematic notions for artificial intelligence research while simultaneously providing a method for how to structure them. As a proof of concept two image schema families are introduced: the Two-Object family and the PATH family. The first deals with spatial relationships between two objects and the latter with dynamic movement of one object. Formally these families will be represented using theory graphs.

The chapter includes considerations and discussions on:

- The Two-Object Family
- Linguistic and psychological motivation behind SOURCE_PATH_GOAL

- The Path Family
- Formal aspects of image schema families

3.1 Family Connections

In Chapter 2 two problems for image schema research were highlighted: The categorisation problem and the structure problem. These problems arise as it is (seemingly) clear that one particular image schema is fine-tuned during cognitive development [1] as well as appear in many different forms later on [2,3].

These problems might remain in psychology and linguistics until a better understanding of the human mind has been acquired. However, in order to utilize image schemas in formal approaches, these problems offer a valuable starting point as for how to solve some of the formal representation issues that arise. Whether or not the modelling becomes entirely cognitively accurate is for the time being deemed less important. Despite the utilised practical approach to image schemas where applicability has higher priority than cognitive accuracy, the suggested approach is motivated and inspired by findings in developmental psychology and cognitive linguistics.

The main claim in this chapter is that image schemas should be considered as members of tightly connected image schema families, where the connecting relation is based on the notion of family resemblance. In particular, each of the image schemas covers a particular conceptual-cognitive scenario within the scope of the schema family. An image schema family may be formally represented as a set (i.e. a *family*) of interlinked theories. This means that the structure problem is approached by clustering similar image-schematic structures together regardless as to where the 'actual' borders for different image-schematic concepts may exists. Likewise, the categorisation problem is approached by ordering the image-schematic structures in respective families based on their internal complexity. This means that an essential notion of this structuring is to understand that for each level in the family hierarchy additional image-schematic elements from either the same or other image schemas are added. This final point also allows for conceptual overlap between different image schema concepts, adding additional angles to the categorisation problem and providing an important point that the literature on image schemas previously have only touched upon.

As proof of concept, two families of image schemas will be introduced. First, the 'Two-Object' family which captures (some of)[4] the static relationships between two objects. The Two-Object family encompass the image schemas CONTACT, SUPPORT and LINK. This is done by inheriting certain conceptual properties from the other

[1] Tim Rohrer. Image schemata in the brain. In Beate Hampe and Joseph E Grady, editors, *From perception to meaning: Image schemas in cognitive linguistics*, volume 29 of *Cognitive Linguistics Research*, pages 165–196. Walter de Gruyter, 2005

[2] Brandon Bennett and Claudia Cialone. Corpus Guided Sense Cluster Analysis: a methodology for ontology development (with examples from the spatial domain). In Pawel Garbacz and Oliver Kutz, editors, *8th International Conference on Formal Ontology in Information Systems (FOIS)*, volume 267 of *Frontiers in Artificial Intelligence and Applications*, pages 213–226. IOS Press, 2014

[3] Dagmar Gromann and Maria M. Hedblom. Breaking Down Finance: A method for concept simplification by identifying movement structures from the image schema Path-following. In *Proceedings of the 2nd Joint Ontology Workshops (JOWO)*, volume 1660, Annecy, France, 2016. CEUR-WS online proceedings

[4] It is likely that relationships that has not been taken into account, exist.

image schemas Verticality and Attraction. It will be demonstrated why this is of importance later in the chapter.

The second family is the 'Path' family, which capture (some of) the dynamic members of the Source_Path_Goal image schema concerning the movement of an object. The Path family ranges from the spatial primitive of basic movement, to more complex image schema notions such as Source_Path and Path_Goal. Higher levels of the family include Movement_In_Loops, which inherits movement related aspects of the image schema Cycle, where the start and end in the Source_Path_Goal schema are interpreted to be identical.

Overlapping image schemas that are combinations of the Path family and another image schema family are, for example, Blockage, Revolving_Movement and Linked_Path. While the chapter touches on the topic of image schema combinations, this will be properly discussed in the upcoming Chapter 5.

The selection of these two families captures the essence of image schemas as they are both spatial and temporal object relations and therefore provide a good foundation to build a proof of concept for further research.

3.2 *The Two-Object Family*

Image schemas have consistently been defined as spatiotemporal relationships between objects and their environment. This means that for any formal representation of image schemas, an important aspect is to formally model relationships between objects. In a natural scenario several objects may play a role, however, for many scenarios it is superfluous to include more than two objects. For now, the relationships between objects are limited to the relationships existing between two objects. Additionally, the formal representation of relationships between two objects can easily be extended to include additional objects were it found to be necessary to model particular scenarios or cognitive phenomena. The image-schematic relationships between two objects that will be considered are Contact, Support and Link. As mentioned, the family graphs are ordered by their internal complexity based on image-schematic components as introduced by Mandler and Cánovas [2014]. In order to successfully construct the Two-Object family, components from additional image schemas need to be 'borrowed'. Therefore, the section starts by introducing two other image schemas, namely Verticality and Attraction.

3.2.1 *Components from* VERTICALITY *and* ATTRACTION

While both VERTICALITY and ATTRACTION are image schemas that belong to their own respective family, it is possible to dissect their components by identifying some core characteristics. Below each image schema will be motivated and the relevant components for the Two-Object family will be extracted.

VERTICALITY*:* VERTICALITY is believed to be one of the earliest image schemas to be learned based on the human body's vertical axis and the perceived effect gravity has on objects [5]. In its static form, VERTICALITY represents orientation and relational notions of above and below. It is a common sight in natural language and conceptual metaphors such as in the expressions 'to stand on higher ground' and 'to feel down'. From a dynamic aspect, VERTICALITY encompasses vertical movement in terms of UP-DOWN. In language, metaphoric expressions such as 'the rise to power' and 'falling from grace' encompass the conceptual metaphors that UP is GOOD/DOWN is BAD while building on the skeleton of VERTICALITY [6].

Image schemas come in different characters (orientational, topological and force-dynamic). VERTICALITY encompasses vertical orientation and it can be argued that it may play a central role in other image schemas. Later it will be illustrated how VERTICALITY is involved in distinguishing members of the Two-Object family, such as CONTACT and SUPPORT. For the current version of the Two-Object family, the only component used from VERTICALITY is 'above'.

ATTRACTION*:* Likewise, image schemas such as ATTRACTION and conceptual structures that encompass conceptual aspects of force (or using Mandler's [2010] words "the feeling of umph") are experienced and conceptualised in the first six months of a child's life. Objects fall to the ground, not because of VERTICALITY in itself, but because of the 'ATTRACTION objects have to the ground'[7]. ATTRACTION can be found in language expressions such as 'I'm drawn to you'. ATTRACTION is part of the force group of image schemas [8] and while it is more complicated than simple 'force towards/from', it can be ascertained that for the purpose of representing simple force relations, ATTRACTION provides a good starting point. For the current purpose, the only conceptual primitive borrowed from the ATTRACTION image schema will be 'force' as in: x puts force on y.

Below conceptual parts of VERTICALITY and ATTRACTION will be included in other image schemas to describe how increasingly complex concepts come about.

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[5] Mark Johnson. *The Body in the Mind: The Bodily Basis of Meaning, Imagination, and Reason*. University of Chicago Press, 1987

[6] Zoltán Kövecses. *Metaphor: A Practical Introduction*. Oxford University Press, Oxford, USA, 2010

[7] Children naturally do not understand gravity, yet they learn to predict that objects are 'forced' downwards.

[8] Mark Johnson. *The Body in the Mind: The Bodily Basis of Meaning, Imagination, and Reason*. University of Chicago Press, 1987

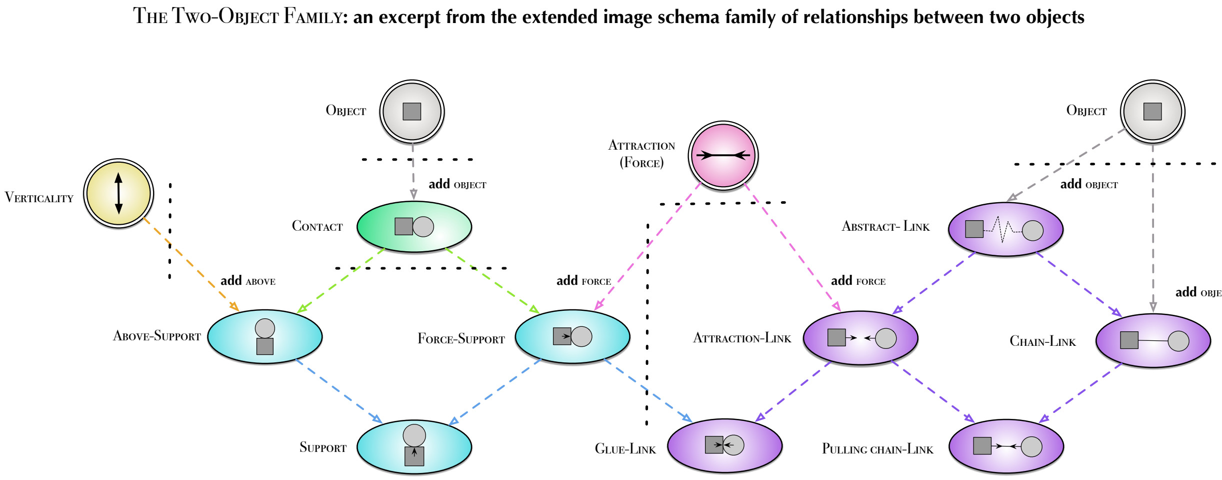

Figure 3.1: How the Two-Object family morphs from Contact to Support and Link through the addition of image-schematic components and integration of Verticality (above) and Attraction (force).

3.2.2 *The Two-Object Family:* Contact, Support *and* Link

The family hierarchy builds on the idea that for each development in the family, additional image-schematic components are added. Working on object relations, this means that at the top of the graph is Object, see Figure 3.1. Note here that Object is represented twice to account for the two merging image-schematic families associated with Contact/Support and the one associated with Link. While Object in itself is not part of a Two-Object family, it is a prerequisite to being able to build object relations between more than one object. Here it is important to note that the branching from each and every member of the graph is in no means intended to be exclusive and exhaustive. The branching from Object to Contact could also contain the branching towards multiple objects in general, in which there exist no Contact relations. This noted, the graph still demonstrates important aspects of relationships between two objects.

Contact*:* Contact is one of the more primitive image schemas involving two objects. In its most general form it represents the object relation in which two (or more) objects are physically touching each other. Figure 3.1 illustrates how image schemas can be conceptually extended by adding specifications from the above-mentioned Verticality and Attraction.

After Contact has been constructed by ensuring contact between two objects, the graph can branch in different directions. One of the most obvious, and presented here, is how Contact can advance into Support.

Support*:* It is unlikely that infants understand the forces behind an image schema like Support. Therefore, in many scenarios it might be sufficient to speak of Support in terms of Contact with 'above' orientation. By merging the image schema Contact with the static form of Verticality (as in 'above') you get an above-Support image schema. For instance, in sentences such as 'the book is on the table' and even the more abstract support 'a shoulder to cry on', what is demonstrated is the orientational relation in which there is Contact and 'above'-ness.

If instead of Verticality, force is added to Contact, force-Support can be distinguished. Here the important aspect is that the supporting object offers physical support, which does not have to be vertical. For instance, a plank that 'leans against a wall' also captures a form of Support. Abstract expressions such as 'offering support to a friend in need' require some abstract form of force, but not really any Verticality. The most accurate and traditional form of Support is constructed when both above-Support and force-Support are combined and a Contact relation is built that has both the traditional 'above'-ness as well as offering the 'physical force' support.

Link*:* The idea that addition of spatial primitives, or image-schematic components, further distinguish the image schemas can also be demonstrated in how Link can be formally constructed to be a small family of different levels of Linkage. After branching out from, arguably the most generic form of Link, namely abstract-Link, the image schema becomes more specific with additions from the notion of force as seen above with how Contact turns into force-Support, or it can go through a third object, a sort of 'chain', generating a chain-Link.

Following the route in which the Link inherits properties from Attraction another abstract Link develops in which there is no physical Contact but instead simply Attraction. It can be described simply using an abstract connection, such as in 'magnetism' (pushing the relationship closer to the conceptualisation of the image schema Attraction) or even in a concept such as 'agreement', but it can also be described using a 'Path' that connects the two objects. A Path is in itself not an Object, but a spatial primitive found in the Source_Path_Goal schema [9] capturing the abstract road that connects the Source with the Goal.

Just like the more complete version of Support, a more complex Link can be created by combing attraction-Link with chain-Link into a concept in which the chain pulls on the connected objects.

Figure 3.1 also demonstrates how two families can overlap. For

[9] George Lakoff and Raphael Núñez. *Where Mathematics Comes From: How the Embodied Mind Brings Mathematics into Being*. Basic Books, New York, 2000

glue-Link, attraction-Link is merged with the properties from the force-Support generating a Link that behaves like 'glue'. For example, the expression 'to be stuck together' demonstrates an abstract form of (involuntary) Linkage[10].

In upcoming Chapter 4, this family will be formalised with the introduction of a logic by which image schemas can be formally represented. Below the understanding of the Source_Path_Goal image schema is expanded on by dissecting it into a Path-following family.

3.3 *The* Path *Family*

The dynamic aspects of image schemas are more complex than the static ones. This means that the build-up to motivate the Path family will go into more depth of both linguistic and psychological research to motivate the members before providing a formalisation in first-order logic with a corresponding theory graph made with Hets .

3.3.1 *From* Source_Path_Goal *to a* Path *Family*

The Classic View of Source_Path_Goal

From the cognitive linguistics point of view, Lakoff and Núñez [2000] present a well worked out perspective of the Source_Path_Goal schema, see Figure 3.2. Their work follows linguistic convention [11] where the moving, active object is called 'trajector' and the goal, or the end destination, is called 'landmark'. In Source_Path_Goal both a direction and a 'purpose' are implied in the image schema, which changes the conceptual nature of the movement. One of the important aspects is what Lakoff and Núñez [2000] call 'elements', or roles, which alter the image schema character, listed in Table 3.1. One of the most important points is the clear distinction between end location and goal, as they distinguish between 'path', the actual trajectory of a movement, and 'route', the expected movement. This means that in the classic view of Source_Path_Goal there is a distinction between End_Path and Goal respective Start_Path and Source. These components are another example of how image schemas are constellations of simpler conceptual blocks that can be added to alter the characteristics of the image schemas.

Cognitive Build-up to Source_Path_Goal

Looking at Source_Path_Goal from the developmental psychology direction, it is possible to distinguish the different stages of how the conceptualisation of the image schema are learned.

[10] The author acknowledges that additional Links may exist that were not here considered.

[11] Leonard Talmy. The fundamental system of spatial schemas in language. In Beate Hampe and Joseph E Grady, editors, *From perception to meaning: Image schemas in cognitive linguistics*, volume 29 of *Cognitive Linguistics Research*, pages 199–234. Walter de Gruyter, 2005

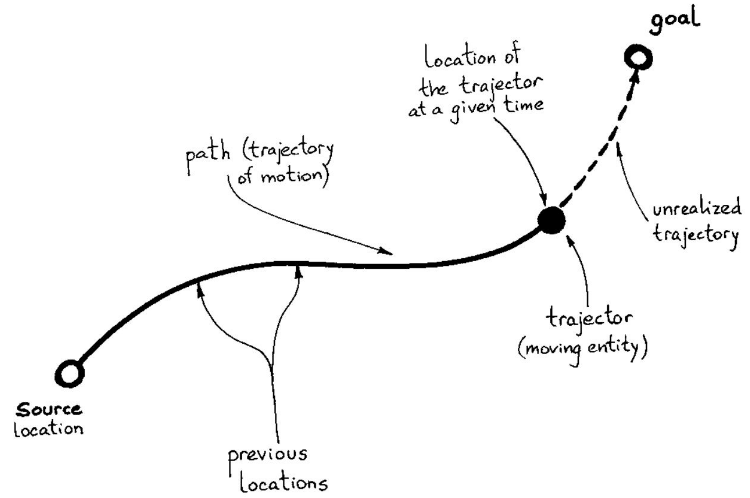

Figure 3.2: The SOURCE_PATH_GOAL schema as illustrated by Lakoff and Núñez [2000].

Element	Description
trajector	The object
source	The initial location
goal	The intended end location
route	A pre-realised route from source to goal
path	The trajectory of motion
position	The position of the trajector at a given time
direction	The direction of the trajector at a given time
end location	End location, may not correspond to the goal location

Table 3.1: Elements of SOURCE_PATH_GOAL according to Lakoff and Núñez [2000]

From a neurological perspective, the processing of objects in motion has higher priority than the processing of static objects. In most scenarios this follows as an obvious consequence to our immediate well being, in other words, to avoid dangerous situations or to interact with potential mates and peers, etc. Thus, it follows that the image schemas concerning the understanding of movement are some of the first to be learned in early infancy [12]. As presented above the Source_Path_Goal image schema implies more than solely movement of objects, as also Lakoff and Núñez [2000] speaks of different elements of the image schema. In order to understand how Source_Path_Goal is fine-tuned and in 'more completion' internally structured, experiments with children have provided some insights on distinguishing how the different members of a Path family may develop.

Mandler [2004] and Mandler and Cánovas [2014] study the Source_-Path_Goal schema from a developmental psychological direction. It is clear that already at an early age children pay more attention to moving objects than resting objects. Trivial as it may seem, it requires children to detect the spatial primitive Object (or Thing) and the temporal schema Movement_Of_Object. Object is understood here in a wide sense that includes not only objects of solid materials, but entities like waves on a pond and shadows. Additionally Mandler and Cánovas [2014] discuss Move as a spatial primitive of its own. However, as both Move and Object are primitives present in all[13] kinds of movement, these two primitives are consistently implied.

The first member of a Path family is the joint relation between Move and Object, namely Movement_Of_Object. It is here to be considered as a temporally dependent image schema since movement by necessity involves a temporal dimension. It is not perceived as a full-fledged 'conceptual primitive', as it always involves at least one spatial primitive , e.i. an object that moves. Another important observation is that children tend to remember movement Paths better than objects themselves. This follows the reasoning by Lakoff and Núñez further indicating that a Path[14] is a spatial primitive, a conceptual primitive disjoint from both Move and from Object.

Keeping things simple, Mandler and Cánovas point out that, although difficult to conceptualise for adults, it is possible for Paths to be non-continuous and there is no need for a goal-directed trajectory. In short, the Path schema could be described as random movement such as in Brownian motion. As image schemas stretch over all senses, a non-visual analogy would be the difference between a sequence of arbitrary noises and a melody and/or a musical scale. The first demonstrates random movement, whereas the latter follows

[12] Tim Rohrer. Image schemata in the brain. In Beate Hampe and Joseph E Grady, editors, *From perception to meaning: Image schemas in cognitive linguistics*, volume 29 of *Cognitive Linguistics Research*, pages 165–196. Walter de Gruyter, 2005

[13] There might be movement scenarios in which Move and/or Object are not present, but for the current purposes these scenarios will be ommitted.

[14] This spatial primitive Path is not to be confused with the collective name for the image schema family Path-following.

a predictable trajectory.

In addition to these two basic spatial primitives, OBJECT and MOVE, and as the child becomes more and more familiar with PATH-following, image schemas that contain more spatial information are learned. This means that in more advanced stages, image schemas may include beyond MOVEMENT_OF_OBJECT and the spatial PATH itself also the spatial primitive END_PATH, and later also a START_PATH [15]. Already at five months, infants can distinguish PATH-following that has an END_PATH (in the PATH family introduced as the image schema 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 [16].

Table 3.2 summarises the spatial primitives that may be involved in image schemas belonging to the PATH-following family. While the content is based on the research of Mandler and Cánovas [2014] minor alterations have been made to better match the terminology in Table 3.1.

Spatial primitive	Description
OBJECT	An object
MOVE	Indication of movement
PATH	The path the object moves along
START_PATH	The initial location
END_PATH	The final location

Table 3.2: Spatial primitives of the PATH-following family according to Mandler and Cánovas [2014].

The distinction, made by Lakoff and Núñez, between the *expected* movement and the *actual* movement is primarily interesting for a description of how image schemas relate to actual events and how new image schemas are learned. Consider, for example, a situation where a child observes the movement of a billiard ball and is surprised that the ball stops because it is blocked by another billiard ball. In this case, a given instance of the MOVEMENT_ALONG_PATH schema formed the expectations of the child, which were disappointed by the actual physical movement, because the expected END_PATH (the goal) does not correspond to the actual END_PATH (end location). Given a repeated exposure to similar events, the child may develop the new image schema, here BLOCKAGE. After learning BLOCKAGE, the child will no longer be surprised by blocked movement since the expected END_PATH (the goal) will correspond to the actual END_PATH (end location)[17]. While the terminological distinction between *expected trajectory* and *actual trajectory* is useful, these do not necessarily need to constitute two different spatial primitives. Indeed, spatial primitives are parts of image schemas and, thus, always parts of conceptualisations, and not parts of actual events.

[15] Jean M. Mandler and Cristóbal Pagán Cánovas. On defining image schemas. *Language and Cognition*, 6(4):510–532, May 2014

[16] Megan Johanson and Anna Papafragou. What does children's spatial language reveal about spatial concepts? Evidence from the use of containment expressions. *Cognitive Science*, 38(5): 881–910, 2014

[17] The stages found in BLOCKAGE are formally approached in Chapter 5

While the notions of PATH-following presented by Mandler and Cánovas and Lakoff and Núñez coincide widely, there are differences in terminology and definitions. In order to keep terminology under control, the present research primarily follows the terminology introduced by the former [18].

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.

3.3.2 *Linguistic Support for* PATH*-following*

This section considers a few examples for concepts which involve members of the PATH-following family.

The most straightforward examples of concepts that involve PATH-following are concepts that are about the spatial relationship of movement between different points. Prepositions such as *from, to, across* and *through* all indicate a kind of PATH-following[19]. This also includes key verbs that describe movement, e.g. *coming* and *going*. Another example, here for the image schema SOURCE_PATH_GOAL, is 'going from Berlin to Prague'. Note that many cases do not provide information about START_PATH and END_PATH of a movement; e.g. 'leaving Berlin' and 'travelling to Berlin' are examples for the image schemas SOURCE_PATH and PATH_GOAL, respectively. 'Meandering' is an example of a concept that realises MOVEMENT_ALONG_PATH, which involves a PATH but no START_PATH or END_PATH. In contrast, no discernible PATH is involved in 'roaming the city', which is an example for MOVEMENT_OF_OBJECT. These examples illustrate that image schemas may be ordered hierarchically with respect to their content: SOURCE_PATH_GOAL contains more spatial primitives and more information than, for example, MOVEMENT_ALONG_PATH, which is the root of the PATH-following family, and MOVEMENT_ALONG_PATH is more specific than MOVEMENT_OF_OBJECT. Figure 3.3 depicts the members and their connections involved in the PATH family.

Beyond concepts that involve movement, PATH-following plays an important role in many abstract concepts and conceptual metaphors. For instance, the concept of 'going for a joy ride' realises the image schema SOURCE_PATH, since it has a START_PATH and a PATH but no END_PATH. Similarly, the expression 'running for president' describes the process of trying to get elected as president metaphorically as a PATH_GOAL. In this metaphor the PATH consists of the various stages of the process (e.g. announcing a candidacy and being nominated by a party) with the inauguration as END_PATH.

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[18] Jean M. Mandler and Cristóbal Pagán Cánovas. On defining image schemas. *Language and Cognition*, 6(4):510–532, May 2014

[19] Some prepositions include other image schemas at the same time. E.g. 'through' involves apart from PATH also some notion of CONTAINMENT. See Chapter 5 for more on image-schematic combinations and overlaps.

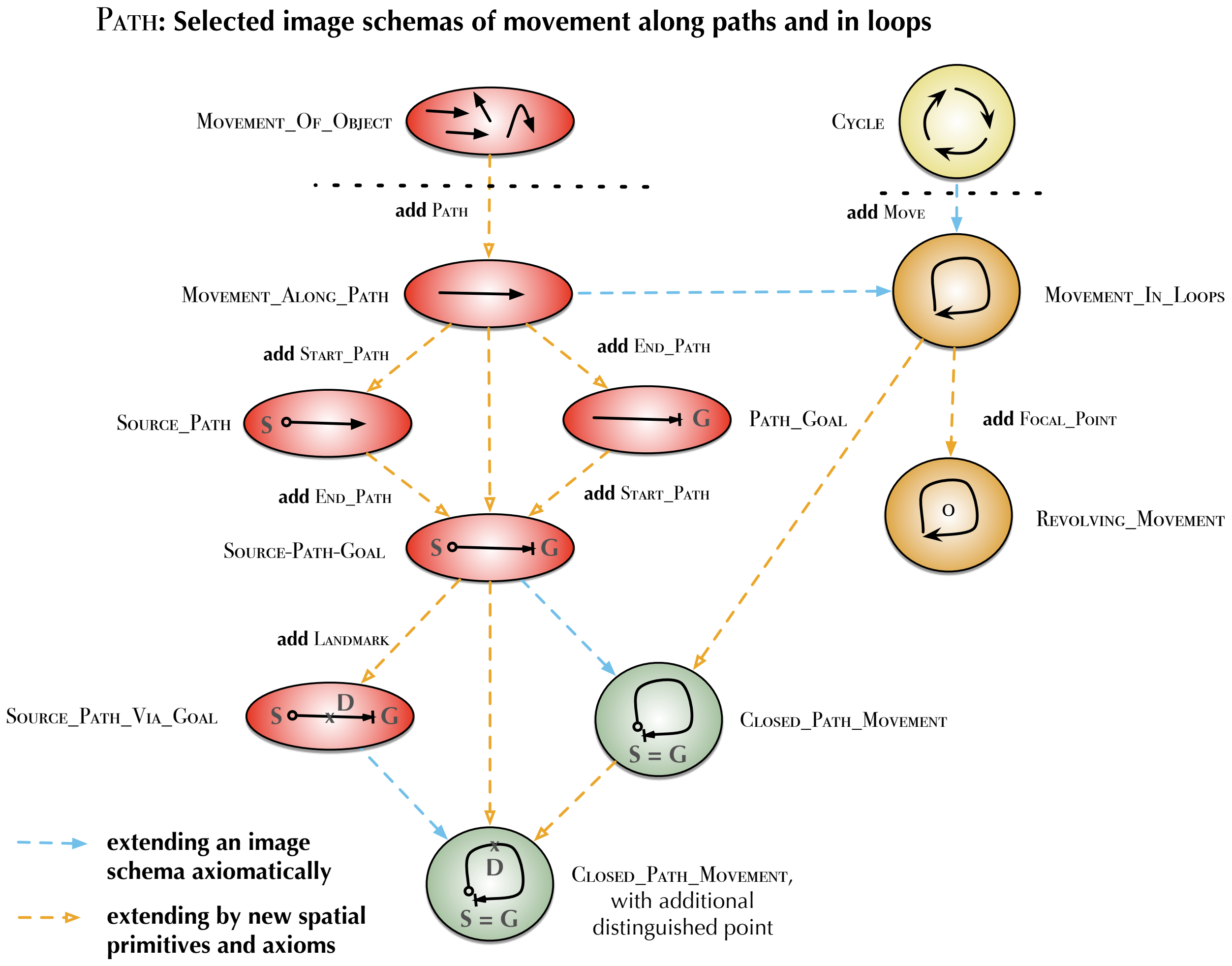

Figure 3.3: Selected image schemas of path and cyclic movement as a graph. The coloured arrows described as "extending an image schema axiomatically" respective "extending by new spatial primitives and axioms", illustrate by which means the PATH family is formally extended. This will be demonstrated in the upcoming chapter.

Another classic conceptual metaphor 'life is a journey', studied by Ahrens and Say [1999], makes an analogical mapping between the passing of time in life, to the passing of spatial regions on a journey. This metaphor gains information from the spatial primitives connected to the image schema SOURCE_PATH_GOAL. Here, the most important spatial primitives are START_PATH and END_PATH. In this metaphor they are mapped to the moments of birth and death, as well as the PATH itself, illustrating how 'life goes on' in a successive motion without 'temporal' branching.

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 also that death gives rise to life, completing a cyclic movement, the image schema MOVEMENT_IN_LOOPS. This image schema can be considered as a version of PATH-following, in which START_PATH and END_PATH coincide at the same 'location'.

	Expression	**Level in hierarchy**
Concrete:	Roaming the city	MOVEMENT_OF_OBJECT
	Meandering	MOVEMENT_ALONG_PATH
	Leaving Berlin	SOURCE_PATH
	Travelling to Berlin	PATH_GOAL
	Going from Prague to Berlin	SOURCE_PATH_GOAL
Abstract:	Going for a joy ride	SOURCE_PATH
	Running for president	PATH_GOAL
	Life is a journey	SOURCE_PATH_GOAL
	The circle of life	MOVEMENT_IN_LOOPS

Table 3.3: Summary of the mentioned expressions and their level in the PATH-following hierarchy.

In the next section this linguistic reasoning will be ontologically represented as a family of movement image schemas.

3.3.3 *From* MOVEMENT_OF_OBJECT *to* CYCLE*: The* PATH *Family*

Based on the support presented in the previous sections, Figure 3.3 contains some of the first basic stages of the image schema family PATH-following. It follows from Mandler's [2004] general definition presented above, of object movement in any trajectory, to increasingly more complex constructions. Below is a breakdown of some of the members.

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 (In Chapter 4, this will be done through 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 and thereby solving the categorisation problems as many image-schematic notions can be part of several 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.

MOVEMENT_OF_OBJECT: The first level of a PATH ontology is the MOVEMENT_OF_OBJECT. This is the instance of PATH-following that contains only the spatial primitives OBJECT and MOVE.

MOVEMENT_ALONG_PATH: The second step in the theory graph in Figure 3.3, is MOVEMENT_ALONG_PATH. This member branches out from MOVEMENT_OF_OBJECT by adding the spatial primitive PATH. The conceptual difference is that here the OBJECT follows a concrete PATH.

In consequence, it is here possible to further describe the relationship between the PATH and the OBJECT, as the OBJECT needs to pass through all the location of the path in (a temporal) order.

SOURCE_PATH and PATH_GOAL: SOURCE_PATH is the result of adding the spatial primitive START_PATH to MOVEMENT_ALONG_PATH. The START_PATH is a location on the PATH is the first location on the path. What distinguishes SOURCE_PATH from other movements is that there is a distinct starting point in the location START_PATH.

Analogously PATH_GOAL can be defined but with and END_PATH instead of a START_PATH.

SOURCE_PATH_GOAL and CLOSED_PATH_MOVEMENT: In the cognitive linguistic literature the SOURCE_PATH_GOAL schema is described as the classic instance of movement [20,21]. In the PATH famliy, this member can be constructed by taking the union of the SOURCE_PATH and the PATH_GOAL schema. This is analogous to the behaviour demonstrated in Section 3.2, where SUPPORT were described as the union of the force-SUPPORT and the attraction-SUPPORT.

CLOSED_PATH_MOVEMENT: The SOURCE_PATH_GOAL image schema may be further specialised by equalising (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

[20] Mark Johnson. *The Body in the Mind: The Bodily Basis of Meaning, Imagination, and Reason*. University of Chicago Press, 1987

[21] George Lakoff and Raphael Núñez. *Where Mathematics Comes From: How the Embodied Mind Brings Mathematics into Being*. Basic Books, New York, 2000

by adding more designated points (i.e. 'landmarks') or other related spatial primitives.

SOURCE_PATH_VIA_GOAL*:* Another member of the family is the SOURCE_PATH_VIA_GOAL. It is a refinement of the SOURCE_PATH_GOAL image schema but with an additional location on the path that the object by necessity must visit.

Following the reasoning presented above, both CLOSED_PATH_MOVEMENT and SOURCE_PATH_VIA_GOAL can be combined in the obvious way. To follow a completely different branch of the family is to look closer at the MOVEMENT_IN_LOOPS.

MOVEMENT_IN_LOOPS *and* REVOLVING_MOVEMENT*:* 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 by merging it with spatial primitives from the CYCLE image schema. The resulting image schema can be further refined by adding the spatial information of a *focal point*, which the path revolves around. This leads to the notion of *orbiting*, or, by continuously moving the orbiting path away from the focal point, to create the concept of *spirals*.

In Figure 3.4 the PATH family is represented as a theory graph made in HETS available on the ontology repository [22] to demonstrate how these graphs look in the ontological scenario.

3.4 *Formal Representation Using Theory Graphs*

Formally, the idea of family structure can be represented as a graph[23] of theories in *The Distributed Ontology, Modeling and Specification Language* (DOL) [24].

Many of the image-schematic representations can be described using logical languages such as Description Logic (DL), First-order Logic (FOL) and the Image Schema Logic (ISL^{FOL}) [25]. However, for image schema families to function as interconnected ontologies a language in which the bridges of the image-schematic structures are taken into account, is required. This is the purpose behind the use of theory graphs.

As mentioned in Chapter 1, DOL is a metalanguage that enables reuse, integration and alignment of existent logical theories, here OMS[26]. A library in DOL consists of basic OMS language modules, such as modules written in the Web Ontology Language (OWL) or Common Logic.

This choice is motivated primarily by two general features of DOL :

[22] `www.ontohub.org`

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

[24] Till Mossakowski, Mihai Codescu, Fabian Neuhaus, and Oliver Kutz. *The Distributed Ontology, Modeling and Specification Language – DOL*, pages 489–520. Springer International Publishing, Cham, 2015b

[25] That will be introduced in the upcoming Chapter 4.

[26] OMS stands for *Ontologies, Models and Specifications modules*, which are defined as logical theories.

(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.

In more detail, DOL aims at providing a unified metalanguage for handling the diversity of ontology, modelling, and specification languages, for which it uses the umbrella term 'OMS'. In particular, DOL includes syntactic constructs for:

1. 'as-is' use of OMS formulated (as a logical theory) in a specific ontology, modelling or specification language, and
2. defining new OMS by modifying and combining existing OMS (which are possibly written in different languages), and
3. mappings between OMS, resulting in networks of OMS.

DOL is equipped with an abstract model-theoretic semantics. The theoretical underpinnings of the DOL language have been described in detail in [Kutz et al., 2010] and [Mossakowski et al., 2012], whilst a full description of the language can be found in [Mossakowski et al., 2015a] or (in a more condensed form) in [Mossakowski et al., 2013].

Building on similar ideas to those underlying the first-order ontology repository COLORE[27] [28], it is here proposed to capture image schemas as interrelated families of (heterogeneous) theories. Similar ideas for structuring commonsense notions have also been applied to various notions of time [29,30]. This general approach also covers the introduction of non-spatial elements such as 'force' as a basic ingredient of image schemas, argued for by for instance Gärdenfors [2007] and Mandler [2010], and constitute the core of some of Mandler and Cánovas's [2014] *conceptual integrations* mentioned in Chapter 2.

3.5 *Chapter Conclusion*

This chapter concerned the notion of how to represent image schemas as families of theories. This is motivated by psychological research in which children can be found to develop and fine-tune the image schemas as they are repeatedly exposed to a particular relationships [31] [32]. Likewise, empirical support from linguistics demonstrated how different language constructions capture different levels of a particular image schema.

Formally these families are represented using theory graphs, in which the image schemas are hierarchically ordered from the most general and by extension through the addition of spatial and concep-

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

[28] Michael Grüninger, Torsten Hahmann, Ali Hashemi, Darren Ong, and Atalay Ozgovde. Modular First-Order Ontologies Via Repositories. *Applied Ontology*, 7(2):169–209, 2012

[29] Johan Van Benthem. *The Logic of Time: A Model-Theoretic Investigation into the Varieties of Temporal Ontology and Temporal Discourse*. D. Reidel Publishing Company, Dordrecht, Holland, 1983

[30] James F. Allen and Patrick J. Hayes. A Common-Sense Theory of Time. In *Proceedings of the 9th International Joint Conference on Artificial Intelligence (IJCAI-85)*, pages 528–531, Los Angeles, CA, USA, 1985

[31] Jean M. Mandler. On the Birth and Growth of Concepts. *Philosophical Psychology*, 21(2):207–230, 2008

[32] Tim Rohrer. Image schemata in the brain. In Beate Hampe and Joseph E Grady, editors, *From perception to meaning: Image schemas in cognitive linguistics*, volume 29 of *Cognitive Linguistics Research*, pages 165–196. Walter de Gruyter, 2005

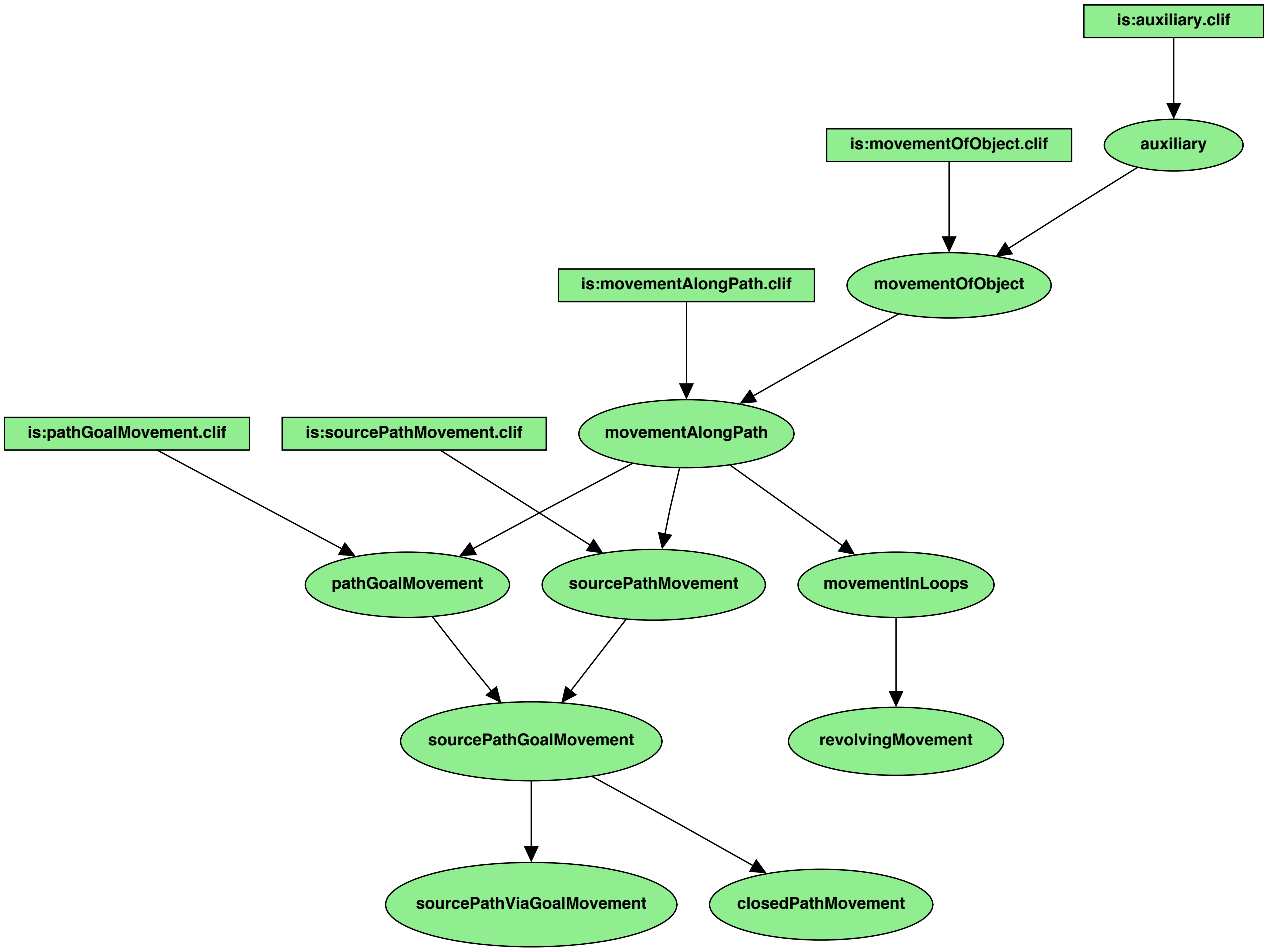

Figure 3.4: Selected image schemas of path and cyclic movement as a theory graph made in Hets.

tual primitives from the same or other image schemas, develops into increasingly more complex constructions.

As a proof of concept, the chapter introduces two important families, the Two-Object family and the PATH family. While the members presented in these families is by no means to be considered exclusive and exhaustive, they capture some of the most essential static relationships between two objects (CONTACT, SUPPORT and LINK) respective some of the dynamic, and temporal, object movements (e.g. MOVEMENT_OF_OBJECT, SOURCE_PATH_GOAL and REVOLVING_MOVEMENT).

In the upcoming chapter, these families will be addressed from a formal perspective through the introduction of the Image Schema Logic ISL^{FOL}, a spatiotemporal combination logic by which the individual image schema members can be formally represented.

4
Introducing ISL^{FOL}: A Logical Language for Image Schemas

The rules of logic are to
mathematics what those of
structure are to architecture.

Bertrand Russell
The Study of Mathematics, 1902

Content and Context

In the previous chapter, image schemas were suggested to be formally represented as families of theories in which spatiotemporal relationships of similar character were hierarchically structured following developmental psychology and empirical support from linguistic expressions. While the family structure is interesting from a cognitive perspective in itself, for image schemas to be integrated into computational concept understanding and invention, a more specific formal representation is required.

As of yet, there exists no clear-cut and satisfactory method to logically approach image schemas. Aiming to rectify this problem, this chapter introduces the Image Schema Logic ISL^{FOL}[1]. The logic is based on previous formalisations of image schemas in which the Region Connection Calculus (RCC) has been demonstrated efficient to model spatial relationships. Simultaneously, the Qualitative Trajectory Calculus (QTC) is used to model relative object movement between objects and Linear Temporal Logic (LTL) is used as a method to capture the sequential dimension of image-schematic events.

The chapter includes considerations and discussions on:

- Problem with formalising image schemas
- Previous formalisation approaches
- Introducing ISL^{FOL}
- A formalisation of the Two-Object family
- A formalisation of the Path-following family

4.1 Formally Dealing with Spatiotemporal Relationships

One of the core ideas of why to formally represents image schemas in the firstplace, is to use them as information skeleton for metaphor, analogies and conceptual blending. Formal systems dealing with analogical transfer, such as HDTP [2], rely on a mostly syntactic pro-

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[1] ISL^{FOL} is a modified version of the ISL^{M} that was introduced in [Hedblom et al., 2017].

[2] Martin Schmidt, Ulf Krumnack, Helmar Gust, and Kai-Uwe Kühnberger. Heuristic-Driven Theory Projection: An Overview. In H. Prade and G. Richard, editors, *Computational Approaches to Analogical Reasoning: Current Trends*, volume 548 of *Computational Intelligence*, pages 163–194. Springer, 2014a

cess that through anti-unification abstract away from predicates as those in FOL. However, there is no innate information in the anti-unification process to determine which inferences from each space in the analogy that belongs to each other, often generating the wrong inference. By providing a formal representation method that diverges from this level of axiomatisation to a more semantically rich method would provide benefits to the automatic interpretation as well as making the formal language more readable to humans. Looking to the state of the art in geographical information science a novel logical language built on the existence of different calculi dealing with spatiotemporal relationships will be introduced. In the upcoming chapter, this formal language for image schemas will be introduced that aims to bridge these problems and better model the semantic content present in the image schemas.

Additionally, it could provide formalised patterns that could be used as ontology design patterns when providing large scale axiomatisations such as seen in [Morgenstern, 2001].

4.1.1 Problems with Formalising Image Schemas

One of the biggest problems in formal image schema research is to find an adequate method by which image schemas should be formalised. While there have been several approaches to formalise image schemas (e.g. Bennett and Cialone [2014], Kuhn [2002], St. Amant et al. [2006]), there exists as of yet no complete formal modelling method to properly represent image schemas. As image schemas are spatiotemporal object relations, few logical representation languages manage to tame all required properties of image schemas alone.

As mentioned, two major problems for successfully formalising image schemas is, first, that they are by definition abstract cognitive patterns, something difficult to capture in formal languages. The second problem is that while it can be argued to be fairly straightforward to capture their static relationships, the dynamic and temporal dimension provides complications in terms of formal representation.

Therefore, this chapter addresses this problem by introducing a novel logic for image schemas using the Eight Region Connection Calculus (RCC-8), Qualitative Trajectory Calculus (QTC) and Linear Temporal Logic (LTL). It is believed that this combination allows for a logic expressive enough to represent image schemas. This is built on the notions presented in Chapter 3, namely that image schemas can be formally represented as families of theories and logically constructed and that by combining elements from different image schema structures increasingly complex concepts can be built (as demonstrated in Chapter 5).

After the syntax and the semantics of the logic has been introduced, the image schema graphs presented in the previous chapter will be formalised using this logic.

4.1.2 *Previous Formalisations of Image Schemas*

Despite image schemas' original status as an abstract, cognitive phenomenon, work on developing a theory and corresponding formalisations has become an increasingly common sight in the context of cognitively-inspired AI. This is mainly due to the prospect of image schemas offering a systematic approach for conceptualisation and concept acquisition based on embodied theories. One major problem, however, is how to formally represent them in an adequate, but still computationally useful way.

Research in AI building on the processing of sensorimotor experiences includes connectionist models as, for instance, described by Regier [1996], which learn to classify visual stimuli into linguistic categories. Similar in approach, but with direct connection to the theory of image schemas, is the work by Nayak and Mukerjee [2012a], who developed a system that, based on video input of OBJECTS moving IN and OUT of containers, learned the concept of CONTAINMENT. Another system is *Dev E-R* which models the sensorimotor stages in cognitive development and fine-tunes its knowledge based on the amount of visual stimuli [3].

More theoretical investigations of how image schemas are involved in formal domains have been reported by Lakoff and Núñez [2000]. They illustrate how image schemas, through the experience of embodied conceptual metaphors, form the foundations for abstract concepts in mathematics. Using basic image-schematic structures such as the PATH-schema they suggest how, for instance, basic arithmetic or a notion of rational numbers can mentally be developed by the child and, taking into account further experiences and image schemas, evolve into increasingly abstract mathematical concepts.

While these and similar efforts demonstrate how the development of abstract concepts may be approached in a constructive way within the framework of cognitive science and image schemas, it does not in itself provide any answers on how to formally treat the problem.

Frank and Raubal [1999] presented a then up-to-date review of attempts to formalise image schemas. They discussed the prospects of representing them with calculi or in function representations, and also proposed a method on how to formally structure image schemas using a relational calculus both on a large-scale as in GIS and small-scale such as a table surface.

Bennett and Cialone [2014] approached the problem from a lin-

[3] Wendy Aguilar and Rafael Pérez y Pérez. Dev E-R: A computational model of early cognitive development as a creative process. *Cognitive Systems Research*, 33:17–41, 2015

guistic and formal perspective. With the desire to map image-schematic language to a logic for ontology development, they searched for synonyms to the Containment image schema (contain, surround, enclose, etc.) in a text corpus from biology. By relating to the well-known RCC-8 topological relations [4], they identified and formally represented eight different kinds of containers. Fuchs [2013] also uses the natural sciences as a domain to identify the role of image schemas. In his work, Fuchs outlines how image schemas are involved in narrative by looking closer at the concept of force as frequently evoked in physics. Fuchs motivates his research not only by the question of how children learn these abstract concepts in infancy but also by how image schema narratives may aid education for adults.

The work by Kuhn [2007] looks at image schemas from a top-down perspective by using noun phrases in WordNet glosses and connects them with spatial abstractions that model image-schematic affordances. Particularly interesting is Kuhn's analysis of nesting and combining image schemas in natural language to represent more complex concepts, e.g. 'transportation' brings together Support and Path. Also interested in the affordances found in image schema is the work by Galton [2010] who used the RCC-6 relations to investigate the affordances and requirements of the Containment schema. This is related to the work by Steedman [2002] who looks at the affordances of going In and Out of rooms given that the doors are either opened or closed. These approaches are particularly interesting as they do not only take the image schema in its static environment into account, but also look at the dynamics of the image schemas in terms of combining Containment with Path.

Other work on formalising image schemas include St. Amant et al. [2006], who combined image schemas using bigraphs to illustrate how different events can be described as series of image-schematic relationships.

The intrinsic difficulty to map the diversity of spatial and temporal formalisms to more commonsense understandings of time and space are well known [5,6]. The approach followed here is to focus the attention on the spatiotemporal modelling of image schemas, and how they give rise to affordances via a formal understanding of how they are understood to participate in/or co-determine, possible actions in an environment.

The nature of the task of modelling image schemas clearly supports the logical pluralism positions defended in [Kutz et al., 2014a]: no single formalism will be sufficient to cover the variety of representations that can be attempted across the array of image schemas and diverse modelling levels. A logical langauge that embrace logi-

[4] David A. Randell, Zhan Cui, and Anthony G. Cohn. A spatial logic based on regions and connection. In *Proceedings of the 3rd International Conference on knowledge representation and reasoning*, 1992

[5] John A. Bateman, Joana Hois, Robert Ross, and Thora Tenbrink. A Linguistic Ontology of Space for Natural Language Processing. *Artificial Intelligence*, 174(14):1027–1071, 2010

[6] Antony Galton. Some problems in temporal knowledge representation. In *Logic and Change, GWAI-92*, Bonn, Germany, September 1992

cal modelling aspects from different calculi and languages would be better suited.

Cognitive Semantics, i.e., empirically supported formal semantics underlying the modelling of image schemas, affordances, and their temporal-dynamic instantiations is seen to provide an interface between the cognitive perspective and logic-based KR approaches. A similar bridge is proposed in hybrid approaches such as Oltramari [2012], who seeks to bridge cognitive 'embodied' features with ontology development.

The *cognitive logics* that are initiated intend to develop a focus on understanding the interplay between the mostly spatial, image-schematic representations, and affordance-based narratives, temporal stories conflicting with the semantics of typical temporal logics.

4.2 *Introducing ISL^{FOL}: The Image Schema Logic*

In general, the rich models of time investigated in more cognitively-driven studies on how humans understand time in poetry, everyday cognition, language in general, and communication can not be mapped easily to existing temporal logic approaches, as demonstrated by, for instance, Pagán Cánovas [2010] and Boroditsky [2000].

The limitations of off-the-shelf calculi also extend to the spatial domain. The well-known Region Connection Calculus (RCC) has been used extensively in qualitative spatial reasoning [7]. However, cognitive studies have supported the claim that humans do not typically make, or accept, some of the distinctions inherent in the RCC calculus [8]. A simpler calculus (usually called RCC-5), can be obtained by removing the distinction between e.g. 'proper part' and 'tangential proper part', while collapsing the logic to pure mereology [9]. At the other end of the spectrum is the work of Bennett and Cialone [2014], who attempted to model the image schema of CONTAINMENT from the linguistic perspective.

The different aspects of the suggested language are introduced under their respective responsibility: *the spatial dimension*, divided into *topology of regions* and *cardinal directions*, *the movement dimension*, divided into relative object movement and points of reference and *the temporal dimension*.

4.2.1 *The Spatial Dimension*

Topology of Regions

Following the work that has been laid out by amongst other Galton [2010] and Bennett and Cialone [2014] the Region Connection Calculus (RCC) is used as a method to represent the spatial relationships

[7] Anthony G. Cohn, Brandon Bennett, John Gooday, and Nick Gotts. RCC: a calculus for region based qualitative spatial reasoning. *GeoInformatica*, 1: 275–316, 1997

[8] Markus Knauff, Reinhold Rauh, and Jochen Renz. A cognitive assessment of topological spatial relations: Results from an empirical investigation. In Stephen C. Hirtle and Andrew U. Frank, editors, *Spatial Information Theory: A Theoretical Basis for GIS*, volume 1329 of *Lecture Notes in Computer Science*, pages 193–206. Springer, 1997

[9] Fritz Lehmann and Antony G. Cohn. The EGG/YOLK reliability hierarchy: Semantic data integration using sorts with prototypes. In *Proceedings of the Conference on Information Knowledge Management*, pages 272–279. ACM Press, 1994

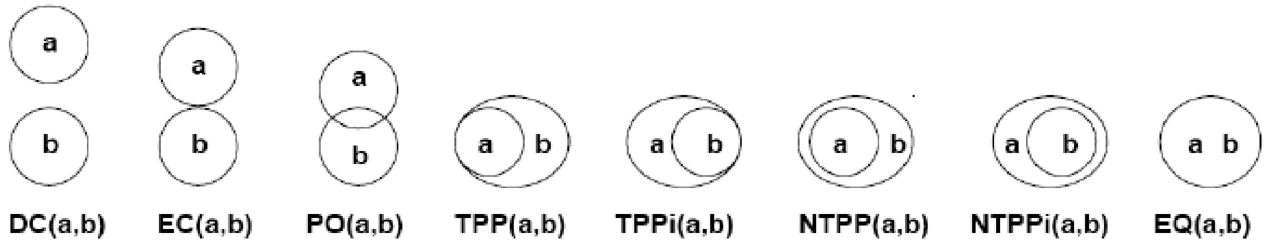

Figure 4.1: The eight RCC-8 relations.

that the image schemas constitute, more precisely the RCC-8 relations, see Figure 4.1 [10]. The reason is that a mere mereology would not suffice for modelling image schemas as it is necessary to distinguish whether two objects touch each other (EC) from them not touching each other (DC).

Cardinal Directions

Directions can be absolute or relative. Usually, left and right denote relative directions [11], which are conceptually and computationally much more complicated than (absolute) cardinal directions [12] like North or West. Here a naive egocentric view (i.e. with a fixed observer that is not part of the model) is assumed, from which directions like left/right, front/behind and above/below can be recognised as cardinal directions. This leads to six binary predicates on objects: *Left*, *Right*, *FrontOf*, *Behind*, *Above* and *Below*. Note that these relations are unions of base relations in a three-dimensional cardinal direction calculus as in [Ligozat, 1998], and the latter can be recovered from these relations by taking suitable intersections and complements (for example, it is possible that none of the above six relations hold, which happens to be the case if two regions are equal or largely overlap).

Point of Reference

As a naive egocentric view based on that all scenarios is presumed to be described also contain a 'perceiver' outside of the model. This means that the perceiver himself, or a subset of his location is provided a point of reference. In order to represent this formally, it is assumed that the perceiver is at a location that can be described as the constant point '*Me*'[13]. In 3D Euclidean space it is intended to take the position $Me = (0, 0, 0)$. This means that objects always move in relation not only to other objects but to an abstract representation of the 'perceiver'. In the case that a perceiver is moving along with an object, then the objects are not perceived to move. For instance, point

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[10] David A. Randell, Zhan Cui, and Anthony G. Cohn. A spatial logic based on regions and connection. In *Proceedings of the 3rd International Conference on knowledge representation and reasoning*, 1992

[11] Alexander Scivos and Bernhard Nebel. The Finest of its Class: The Natural, Point-Based Ternary Calculus $\mathcal{LR}$ for Qualitative Spatial Reasoning. In *Spatial Cognition*, pages 283–303, 2004

[12] Gérard Ligozat. Reasoning about cardinal directions. *J. Vis. Lang. Comput.*, 9(1):23–44, 1998

[13] The constant name *Me* is used to put emphasis on that this reference point is at a perceiver.

Me moves together with an object such as a car, given that a person is inside a moving car. This follows the intuition that it is the outside of the car that moves rather than the car itself.

4.2.2 *The Movement Dimension*

In order to take the dynamic aspects of the image schemas into account the Qualitative Trajectory Calculus (QTC) [14] is used to represent how two objects relate in terms of movement. In its variant QTC$_{B1D}$, the trajectories of objects are described in relation to one another. QTC works on relative movement between disjoint 'moving point objects'. While Weghe et al. [2006] use nine different relations[15], these are composed of two independent parts, with three possibilities for each part. The calculus is here simplified by only considering these three possibilities:

- if object O_1 moves towards O_2's position, this is represented as: $O_1 \rightsquigarrow O_2$,
- if O_1 moves away from O_2's position, this is represented as: $O_1 \hookleftarrow O_2$
- while O_1 being at rest with respect to O_2's position is expressed as: $O_1 \mid\circ O_2$.

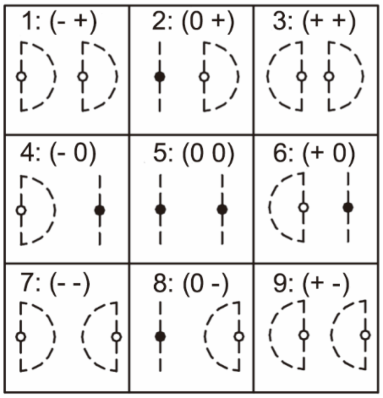

Figure 4.2: The relationship between moving objects in QTC [Chavoshi et al., 2015].

This way of writing the relative movement of two objects is intuitive and expressive. Arguably, one could claim that if one object moves away from the another object, both could be perceived as moving away from the each other. But as a naive egocentric view is presupposed, one object will remain in a fixed position in regards to the perceiver. The calculus of Weghe et al. [2006] can be recovered by taking intersections of these relations, combining the description of the movement of O_1 with respect to O_2's position with the description of the movement of O_2 with respect to O_1's position. For example, $O_1 \rightsquigarrow O_2 \wedge O_2 \hookleftarrow O_1$ is denoted as O_1-+O_2 in [Weghe et al., 2006].

Secondly, in the current scenario, where extended regions modelled in RCC are considered as the spatial objects subjected to 'relative movement', here an appropriate definition of the 'location' of an object is needed in order to meaningfully measure the distance between two regions. Note that in the original QTC calculus spatial objects are abstracted to points in space, and therefore the problem there does not arise. This is further discussed in Section 4.2.5, which is devoted to the semantics of ISL^{FOL}.

With QTC, it is possible to speak about relative movement for a given time point. What is missing is the ability to speak about the future.

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[14] Nico Van De Weghe, Anthony G. Cohn, Guy De Tré, and Philippe De Maeyer. A qualitative trajectory calculus as a basis for representing moving objects in geographical information systems. *Control and cybernetics*, 35(1): 97–119, 2006

[15] The reason for using nine relations is the wish to obtain a partition of the space of all relations between two objects, as is usually done in qualitative spatial reasoning.

4.2.3 *The movement dimension – paths*

Note that QTC has been defined for DC objects only, and technically, all QTC relations between two objects imply that these are DC. This is generalised to objects in that are in arbitrary RCC8 relation. This needs an adaptation of the QTC semantics, see below.

Dependent on situation, the distance between objects can, and needs to be, calculated differently. For instance, the distance between two regions can be based on the usual Euclidean distance d:

$$d(Y, Z) = \inf\{d(y, z) \mid y \in Y, z \in Z\}$$

The distance can be calculated from the shortest possible distance between objects. This is the kind of distance needed when two objects are in contact with each other (EC). For instance, imagine a ball rolling off a table, the ball is in contact with the table until the minimal distance between the objects exceeds 0. Or it can be calculated based on the maximal distance. In the case that the objects are overlapping (PO) or to become proper parts (PP), as would be the case in several forms of CONTAINMENT, a combinations of these two points are needed. Imagine if you drop a ball into a basket. The ball will not stop its movement, until it hits the 'back of the basket' with the 'front' of the ball. This form of going INTO a container, also imply blockage. However, for many forms of CONTAINMENT it is enough to describe how one object 'overlaps' the region of another object. For this it is possible to calculate distance based on the geometric centre, centroid C, of the object:

The centroid of a finite set of k points $x_1, x_2, \ldots, x_k$ in $\mathbb{R}^n$ is:

$$C = \frac{x_1 + x_2 + \cdots + x_k}{k}$$

For now ISL^{FOL} is limited to calculating the distance between objects based on the geometric centre, but for future extension different distance calculations are needed to be accounted for.

4.2.4 *The Temporal Dimension*

For temporal representation, the simple linear temporal logic (LTL) over the reals is used [16,17].

The syntax is as follows:

$$\varphi \ ::= \ p \quad \mid \top \mid \neg\varphi \mid \varphi \wedge \varphi \mid \varphi \mathbf{U} \varphi \mid \exists x{:}s \,.\, \varphi$$

$\varphi \,\mathbf{U}\, \psi$ reads as "φ holds, until ψ holds". U associates to the right, that is, $\varphi \,\mathbf{U}\, \psi \,\mathbf{U}\, \chi$ is parsed as $\varphi \,\mathbf{U}\, (\psi \,\mathbf{U}\, \chi)$. As is standard in temporal logic, the following derived operators can be defined:

[16] Fred Kröger and Stephan Merz. *Temporal Logic and State Systems (Texts in Theoretical Computer Science. An EATCS Series)*. Springer, first edition, 2008

[17] Mark Reynolds. The complexity of temporal logic over the reals. *Annals of Pure and Applied Logic*, 161(8):1063 – 1096, 2010

- $\mathbf{F}\varphi$ (at some time in the future, φ) is defined as $\top\mathbf{U}\varphi$,
- $\mathbf{G}\varphi$ (at all times in the future, φ) is defined as $\neg\mathbf{F}\neg\varphi$.
- $\forall x{:}s\,.\,\varphi$ as $\neg\exists x{:}s\,.\,\neg\varphi$

Moreover, for material implication $\rightarrow$ is used and $\leftrightarrow$ is used for biimplication, while $\veebar$ is used for the exclusive or.

4.2.5 *The Combined Logic* ISL^{FOL}

Syntax of ISL^{FOL}

The syntax of ISL^{FOL} is defined over the combined languages of RCC-8, QTC$_{B1D}$, cardinal direction (CD), first-order logic and linear temporal logic (LTL) over the reals, with 3D Euclidean space assumed for the spatial domain. Note that we need LTL over real-time in order to interpret QTC relations, the semantics of which assumes continuous time. ISL^{FOL} therefore stands for '**I**mage **S**chema **L**ogic' and $M = \langle$RCC-8$, QTC_{B1D}, CD, LTL,$ 3D-Euclid$\rangle$. The combination of the spatial and temporal modalities follows the temporalisation strategy of Finger and Gabbay [1993].

Signatures (vocabularies) are built over the fixed set of three sorts $S = \{Object, Region, Path\}$. A signature $\Sigma = (F_r, F_f, P_r, P_f)$ consists of a many-sorted (over sorts S) first-order signature (F_r, P_r) of rigid function and predicate symbols and one (F_f, P_f) of flexible function and predicate symbols. Here, each function symbol is typed with an arity $w \rightarrow s$ and each predicate symbol with an arity w, where $w \in S^*$ is the string of argument sorts and $s \in S$ is the result sort. Overloading is not allowed, that is, each symbol must have unique arity and rigidity. In the context of modelling image schemas, though not playing a central role in the present work, rigid symbols will be useful to handle the modelling of objects that do not change their position nor their extension during a period of time (like a house), while flexible symbols will be useful for modelling objects that essentially have to change (like a moving ball or a balloon being inflated).

Σ-**Sentences** are first-order LTL temporal formulas (see Section 4.2.4) built over (ground) atomic formulas taken from the union of RCC-8 statements (see Section 4.2.1), 3D cardinal directions (see Section 4.2.1), QTC$_{B1D}$ (see Section 4.2.2), and standard first-order application of predicates.

Let X be an S-sorted set of variables, that is, X is a triple of sets $(X_{Object}, X_{Region}, X_{Path})$. In parallel for all $s \in S$, the set $T_s(X)$ of terms of sort $s \in S$ is defined to be the least set such that:

- Me is a term $Me \in T_{Region}$,

- if $x \in X_s$, then $x \in T_s(X)$ (variables are terms),
- if $f : w \to s \in F_r \cup F_f$ and $t_1 \in T_{s_1}(X), \dots, t_n \in T_{s_n}(X)$, then $f(t_1, \dots, t_n) \in T_s(X)$ (terms are closed under application of function symbols),
- if $t \in T_{Object}(X)$, then $t \in T_{Region}(X)$ (objects can be implicitly coerced to the region they occupy),
- if $t \in T_{Path}(X)$, then $source(t), goal(t) \in T_{Region}(X)$ (the source and the target of a path are (one-point) regions).

The set of atomic formulas contains

- $t = u$ for $t, u \in T_s(X)$,
- $p(t_1, \dots, t_n)$ for $p : w \in P_r \cup P_f$ and $t_1 \in T_{s_1}(X), \dots, t_n \in T_{s_n}(X)$,
- $DC(t,u)$, $EC(t,u)$, $OV(t,u)$, $EQ(t,u)$, $TPP(t,u)$, $TPPi(t,u)$, $NTPP(t,u)$, $NTPPi(t,u)$, for terms $t, u \in T_{Region}(X) \cup T_{Path}(X)$,
- $Left(t,u)$, $Right(t,u)$, $FrontOf(t,u)$, $Behind(t,u)$, $Above(t,u)$, $Below(t,u)$, for terms $t, u \in T_{Region}(X) \cup T_{Path}(X)$,
- $t \rightsquigarrow u$, $t \hookleftarrow u$, $t \mid\!\circ\; u$, for terms $t \in T_{Object}$, $u \in T_{Region}(X)$.

ISL^{FOL}-fomulas are first-order LTL formulas (See Section 4.2.4) over these atomic formulas.

Here are a few examples of well-formed sentences that can be written in this language (and might be considered true in specific scenarios). Note, however, that none of them are valid (i.e. true in all models), but can be valid in scenarios where the geometry of objects and possible movements are further restricted in the description of the semantics, or can alternatively be used to prescribe admissible models.

- $FrontOf(a,b) \wedge \mathbf{F}\neg FrontOf(a,b) \longrightarrow \mathbf{F}(a \rightsquigarrow b \vee a \hookleftarrow b \vee b \rightsquigarrow a \vee b \hookleftarrow a)$ ‘If a is in front of b, but ceases to be so in the future, then sometime in the future, either a or b must move with respect to the other object’s original position’;
- $Above(a,b) \wedge \mathbf{G}a \mid\!\circ\; b \longrightarrow \mathbf{G}Above(a,b)$ ‘If a is above b and never moves relative to b, it will be always above b’. Note that this sentence is not valid: consider e.g. that a circles around b with constant distance. However, it holds if for example a and b always stay on the same line (that is, their relative movement is 1D only);
- $DC(a,b) \wedge \mathbf{G}a \hookleftarrow b \longrightarrow \mathbf{G}DC(a,b)$ ‘If a is disconnected to b and always moves away from it, it will always stay disconnected to b’. This is actually a validity.

The Semantics of ISL^{FOL}

The combined logic ISL^{FOL} is interpreted spatially over regions in $\mathbb{R}^3$ and temporally over the real line. Note that continuous time is needed in order to interpret QTC properly.

An interpretation (model) M consists of:

- a non-empty set M_{Object}, which is the universe of discourse,
- the fixed interpretation M_{Region} as set of all subsets of $\mathbb{R}^3$,[18]
- the fixed interpretation M_{Path} as set of all paths in 3D space, i.e. of all continuous functions $[0,1] \to \mathbb{R}^3$,
- a function $f_M : M_w \to M_s$[19] for each rigid function symbol $f : w \to s \in F_r$,
- a function $f_M : \mathbb{R} \times M_w \to M_s$ for each flexible function symbol $f : w \to s \in F_f$,
- a relation $p_M \subseteq M_w$ for each rigid predicate symbol $p : w \in P_r$,
- a relation $p_M \subseteq \mathbb{R} \times M_w$ for each flexible predicate symbol $p : w \in P_r$,
- a function $occupies_M : \mathbb{R} \times M_{Object} \to M_{Region}$, mapping each object to the region it occupies (at a certain time).

Given a set of variables $X = (X_{Object}, X_{Region}, X_{Path})$, a variable valuation $\nu : X \to M$ consists of three functions: $\nu = (\nu_{Object} : X_{Object} \to M_{Object}, \nu_{Region} : X_{Region} \to M_{Region}, \nu_{Path} : X_{Path} \to M_{Path})$.
Given a term $t \in T_s(X)$, a variable valuation $\nu : X \to M$ and a time point $\tau \in \mathbb{R}$, its evaluation $[t]_{M,\nu,\tau,s}$ is defined as follows:

- $[Me]_{M,\nu,\tau,s} = (0,0,0)$
- $[x]_{M,\nu,\tau,s} = \nu_s(x)$
- $[f(t_1,\ldots,t_n)]_{M,\nu,\tau,s} = f_M(\tau, [t]_{M,\nu,\tau,s}, \ldots, [t]_{M,\nu,\tau,s})$,[20]
- $[t]_{M,\nu,\tau,Region} = occupies_M(\tau, [t]_{M,\nu,\tau,Object})$ if $t \in T_{Object}(X)$,
- $[source(t)]_{M,\nu,\tau,Region} = \{[t]_{M,\nu,\tau,Path}(0)\}$,
- $[goal(t)]_{M,\nu,\tau,Region} = \{[t]_{M,\nu,\tau,Path}(1)\}$.

Given a formula φ, a variable valuation $\nu : X \to M$ and a time point $\tau \in \mathbb{R}$, its satisfaction $M, \nu, \tau \models \varphi$ is defined as follows. If φ is an atomic formula, then we define

- $M, \nu, \tau \models t = u$ if $[t]_{M,\nu,\tau,s} = [u]_{M,\nu,\tau,s}$,
- $M, \nu, \tau \models p(t_1,\ldots,t_n)$ if $(\tau, [t]_{M,\nu,\tau,s}, \ldots, [t]_{M,\nu,\tau,s}) \in p_M$,[21]

[18] Usually, RCC8 is restricted to regular closed sets. However, for the current purposes it should cover images of paths and source and target points of paths as well, and these are not regular closed.

[19] If $w = s_1 \ldots s_n$, then $M_w = M_{s_1} \times \cdots \times M_{s_n}$.

[20] The argument τ needs to be dropped for rigid function symbols.

- If R is an RCC-8 relation, $M, \nu, \tau \models R(t, u)$ holds if $[t]_{M,\nu,\tau,Region}$ is in relation R with $[u]_{M,\nu,\tau,Region}$, following the RCC-8 semantics in [Randell et al., 1992]. Here, a path tacitly converts into its image in $\mathbb{R}^3$ in order to get a region.

- if R is a cardinal direction relation, then
  - $M, \nu, \tau \models Left(t, u)$ holds if $\inf\{x \mid (x, y, z) \in [u]_{M,\nu,\tau,Region}\} \geq \sup\{x \mid (x, y, z) \in [t]_{M,\nu,\tau,Region}\}$.
    $M, \nu, \tau \models Right(t, u)$ holds if $M, \nu, \tau \models Left(s, r)$ holds.
  - $M, \nu, \tau \models FrontOf(t, u)$ holds if $\inf\{y \mid (x, y, z) \in [u]_{M,\nu,\tau,Region}\} \geq \sup\{y \mid (x, y, z) \in [t]_{M,\nu,\tau,Region}\}$.
    $M, \nu, \tau \models Behind(t, u)$ holds if $M, \nu, \tau \models FrontOf(s, r)$ holds.
  - $M, \nu, \tau \models Above(t, u)$ holds if $\inf\{z \mid (x, y, z) \in [t]_{M,\nu,\tau,Region}\} \geq \sup\{z \mid (x, y, z) \in [u]_{M,\nu,\tau,Region}\}$.
    $M, \nu, \tau \models Below(t, u)$ holds if $M, \nu, \tau \models Above(s, r)$ holds.

- QTC_{B1D} formulas are interpreted as in [Weghe et al., 2006], but over regions as moving objects. More specifically, distance between objects is calculated from their defined geometric centre. For $R \in M_{Region}$, set $C_R = (c_x, c_y, c_z)$, where

  $$\begin{aligned} c_x &= \tfrac{1}{2}(\inf\{x \mid (x, y, z) \in R\} + \sup\{x \mid (x, y, z) \in R\}) \\ c_y &= \tfrac{1}{2}(\inf\{y \mid (x, y, z) \in R\} + \sup\{y \mid (x, y, z) \in R\}) \\ c_z &= \tfrac{1}{2}(\inf\{z \mid (x, y, z) \in R\} + \sup\{z \mid (x, y, z) \in R\}) \end{aligned}$$

  Then, for regions $R, S \in M_{Region}$, their distance is the Euclidean distance for the centres

  $$d(R, S) = d(c_R, c_S).$$

  Then, given terms t and u, exactly one of three cases occurs:
  - $M, \nu, \tau \models t \rightsquigarrow u$ iff t (a potentially moving object) is moving towards u (a non-moving region), that is, if[22]
    $\exists \tau_1 (\tau_1 < \tau \wedge \forall \tau^- (\tau_1 < \tau^- < \tau \rightarrow d([t]_{M,\nu,\tau^-,Region}, [u]_{M,\nu,\tau,Region}) > d([t]_{M,\nu,\tau,Region}, [u]_{M,\nu,\tau,Region}))) \wedge$
    $\exists \tau_2 (\tau < \tau_2 \wedge \forall \tau^+ (\tau < \tau^+ < \tau_2 \rightarrow d([t]_{M,\nu,\tau,Region}, [u]_{M,\nu,\tau,Region}) > d([t]_{M,\nu,\tau^+,Region}, [u]_{M,\nu,\tau,Region})))$
  - $M, \nu, \tau \models t \hookleftarrow u$ iff t is moving away from u, that is, if
    $\exists \tau_1 (\tau_1 < \tau \wedge \forall \tau^- (\tau_1 < \tau^- < \tau \rightarrow d([t]_{M,\nu,\tau^-,Region}, [u]_{M,\nu,\tau,Region}) < d([t]_{M,\nu,\tau,Region}, [u]_{M,\nu,\tau,Region}))) \wedge$
    $\exists \tau_2 (\tau < \tau_2 \wedge \forall \tau^+ (\tau < \tau^+ < \tau_2 \rightarrow d([t]_{M,\nu,\tau,Region}, [u]_{M,\nu,\tau,Region}) < d([t]_{M,\nu,\tau^+,Region}, [u]_{M,\nu,\tau,Region})))$

---

[22] Recall that $[t]_{M,\nu,\tau,Region} = occupies_M(\tau, [t]_{M,\nu,\tau,Object})$.

  - $M, \nu, \tau \models t \mid\!\circ\, u$ iff t is of stable distance with respect to u, that is, in all other cases. Note that stable distance does not imply absence of relative movement. For example, consider that t moves around u but keeps the distance stable (e.g. a satellite moves around the earth).

Satisfaction of complex formulas is inherited from LTL:

- for atomic p, $M, \nu, \tau \models p$ has been defined above
- $M, \nu, \tau \models \neg\varphi$ iff not $M, \nu, \tau \models \varphi$
- $M, \nu, \tau \models \varphi \wedge \psi$ iff $M, \nu, \tau \models \varphi$ and $M, \nu, \tau \models \psi$
- $M, \nu, \tau \models \varphi \mathbf{U} \psi$ iff for some $\rho > \tau$, $M, \nu, \rho \models \psi$ and $M, \nu, \sigma \models \varphi$ for all $\sigma \in [\tau, \rho)$.
- $M, \nu, \tau \models \exists x.\varphi$ if there exists some valuation $\xi : X \to M$ differing from ν at most for x, such that $M, , \xi, \tau \models \varphi$.

Finally, φ holds in M, denoted $M \models \varphi$, if for all time points $t \in \mathbb{R}$ and all valuations $\nu : X \to M$, then $M, \nu, \tau \models \varphi$.[23]

Now that ISL^{FOL} is introduced as a formal language for image schemas that can be used to describe both spatial and temporal dimensions of the image schemas, the members of the Two-Object family will be formalised followed by a formalisation of some of the members in the PATH family.

4.3 *Formalising the Two-Object Family*

In Chapter 3 the Two-Object family was properly introduced as a method to formally structure the image schemas that encompass two objects and their physical relationship to one another.

In that chapter, Figure 3.1 (see Figure 4.4 for a smaller version) illustrates how the image schemas involving two objects can be formally developed by adding specifications such as above orientation and force. The illustration show how both CONTACT and LINK can be further developed and interconnected with one another.

In the next section, these notions will be formally represented using ISL^{FOL}.

4.3.1 *Formalising* CONTACT, SUPPORT *and* LINK

CONTACT*:* As previously demonstrated, CONTACT is the most general image schema in which two objects have a (physical) connection to each other. While there exists disagreement to as whether OBJECT should be considered an image schema in itself or rather a spatial primitive [24,25], it needs to be part of the formal representation.

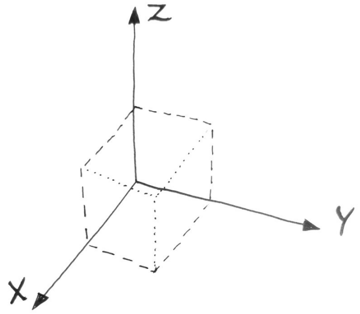

Figure 4.3: Illustration of euclidean space.

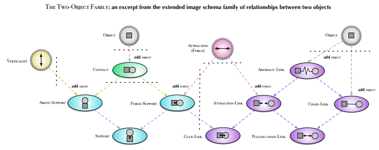

Figure 4.4: The Two-Object family. See Chapter 3 and Figure 3.1 for more details.

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[23] Note, that in order to keep the semantics simpler and in a first-order paradigm, only quantification over rigid objects are allowed.

[24] Jean M. Mandler and Cristóbal Pagán Cánovas. On defining image schemas. *Language and Cognition*, 6(4):510–532, May 2014

[25] Francisco Santibáñez. The object image-schema and other dependent schemas. *Atlantis*, 24(2):183–201, 2002

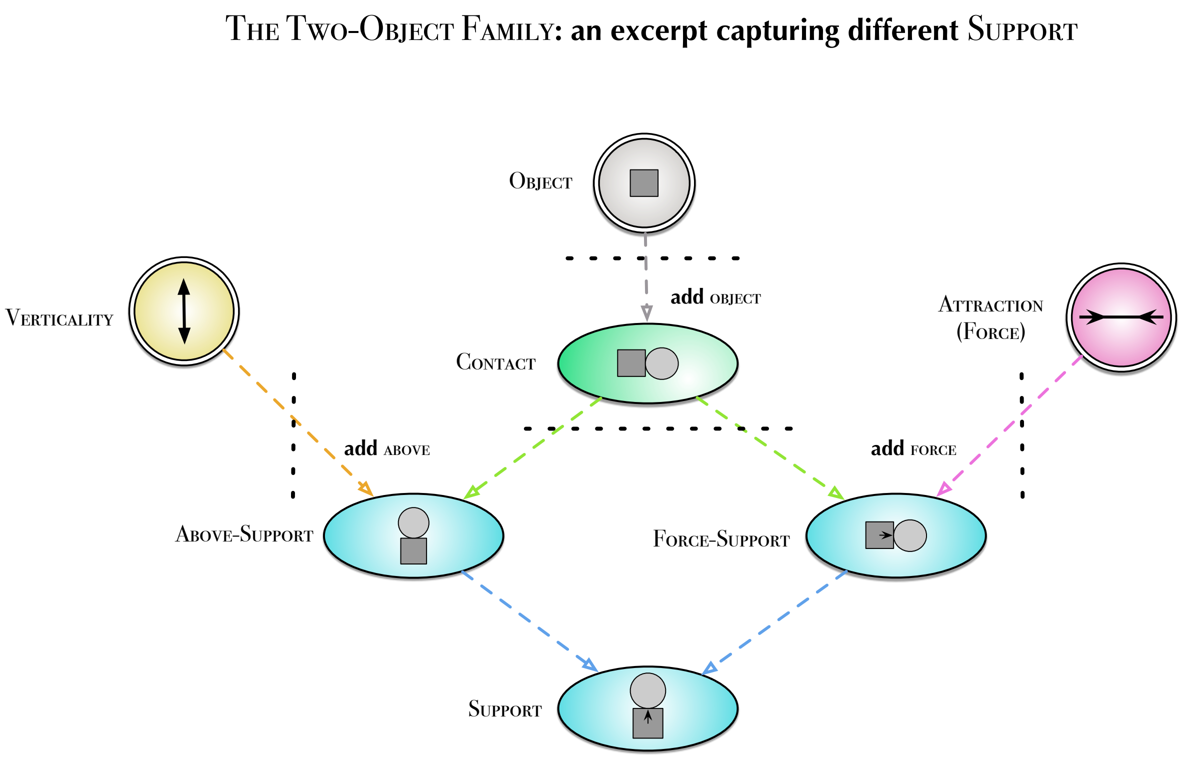

Figure 4.5: Subset of the Two-Object Family: Constructing the different Support schemas.

For Contact, the relationship is without any force dynamics neither does it contain any topological or orientational requirements.

Contact is formalised as two regions, here represented by object names (O_1 and O_2) touching, which is represented in RCC-8 as:

$$\forall O_1, O_2{:}Object\ (\textsc{Contact}(O_1, O_2) \leftrightarrow \neg DC(O_1, O_2))$$

This must also be defined for the relationship between objects and regions:

$$\forall O{:}Object, \forall R{:}Region\ (\textsc{Contact}(O, R) \leftrightarrow \neg DC(O, R))$$

Alternatively, it is possible to use $EC(O_1, O_2)$ instead of the $\neg DC(O_1, O_2)$. However, by saying that objects are in contact with each other when they are not disjoint includes also overlapping objects. Which naturally is important in many scenarios. For instance, one can argue whether objects inside a room are in Contact with the room or not. However, for now the region an object occupies is a good enough approximation to use when describing relationships such as Contact.

Support: Following the branching in Figure 3.3, Support offers a slightly more complicated formalisation as either Attraction or 'force' and/or VERTICALITY and 'above'-ness are involved to keep one object in contact with the other object. Visualise a table that offers counter-force for books on top of it, or a wall that offers SUPPORT for any object resting on the wall.

In order to properly differentiate between CONTACT and SUPPORT it is essential to introduce 'above' and 'force' as conceptual primitives.

Formalising Above and Force: VERTICALITY in terms of above (and below) orientation is expressed with the following predicate (see Section 4.2.5 for details):

$$Above(\ldots,\ldots)$$

Where the first is above the second variable.

The spatial relationship in 'the book is on the table' can be described writing $Above(book, table)$ together with $\textsc{Contact}(book, table)$.

In order to continue with the image schemas, ATTRACTION or 'force' is of essence to include for many of the image schema, including SUPPORT (see Figure 4.5). From a developmental psychology perspective, it is unintuitive to formalise the full understanding of the physical laws and forces that are present in our world. However, even children early understand that forces are part of how objects relate to one another and their environment. An inaccurate but fairly straightforward way to approach 'force' would be to look at how force relates to movement, e.g. how gravity pulls the book towards the centre of the planet and how the table simply hinders this movement, in other words, SUPPORTS it. However, it is unlikely that children have any comprehension of any notion in which a book is 'moving towards the centre of the Earth' as it appears to simply rest on the table. What they do seem to comprehend is that a table will offer the book a surface to rest on.

Following the introduced notion of image schema primitives the force relation is written as follows:

$$\mathsf{forces}(\ldots,\ldots)$$

Where the first puts force on the second variable.

Advancing down in the hierarchy of the CONTACT side of the Two-Object family the two weaker SUPPORT versions are formalised: Above-SUPPORT and Force-SUPPORT.

$$\forall O_1, O_2{:}Object\ (Above\text{-}\textsc{Support}(O_1, O_2) \leftrightarrow EC(O_1, O_2) \wedge Above(O_1, O_2))$$

$$\forall O_1, O_2{:}Object\ (Force\text{-}\textsc{Support}(O_1, O_2) \leftrightarrow EC(O_1, O_2) \wedge \mathsf{forces}(O_1, O_2))$$

When these two image-schematic structures are merged together the union correspond to the universal and more complete image schema of SUPPORT.

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

LINK*:* In order to formalise LINK to the full complexity that is involved, a richer logic than that presented in this chapter is needed. However, the core of LINKage is not the flexibility in terms of how a link can be bent, stretched, etc. but rather that there is a link in the first place. As motivated in the previous chapter there are several kinds of LINKS (see Figure 4.6). For now, the formalisation of LINK is limited to those that are part of the CONTACT branching, glue-LINK and the previous step in the hierarchy, the Attraction-LINK.

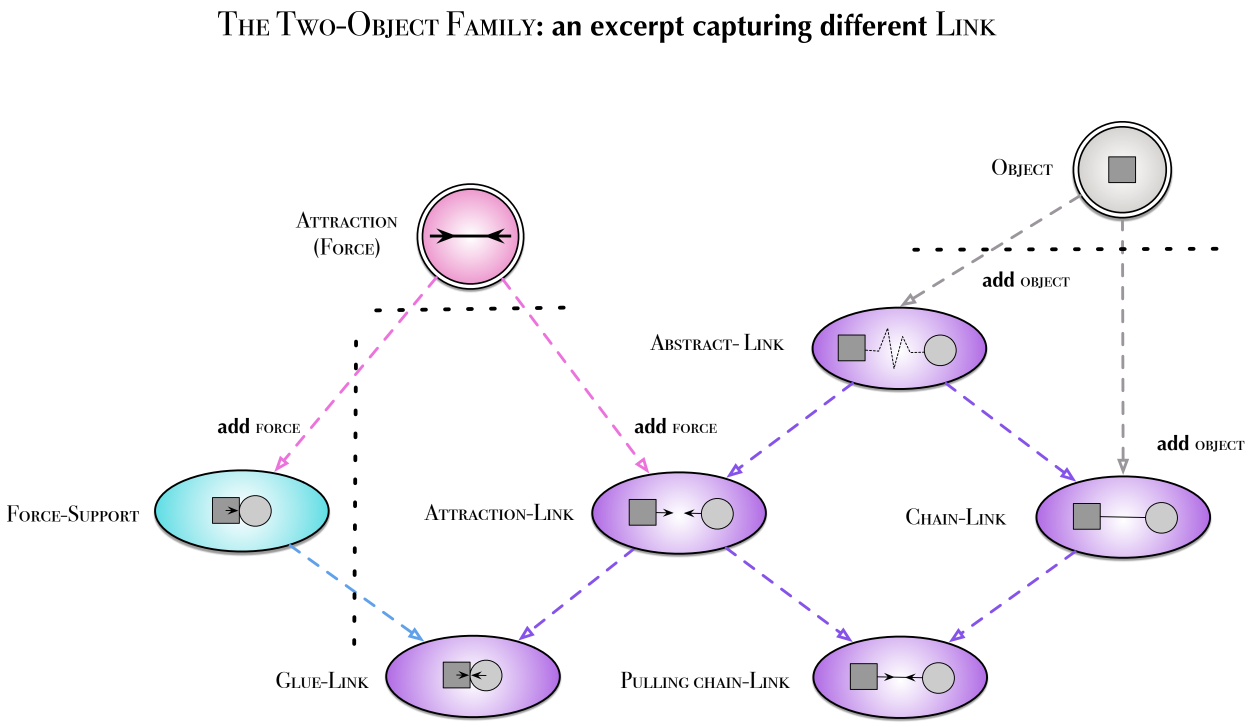

Figure 4.6: Subset of the Two-Object Family: Constructing the different LINK schemas.

$$\forall O_1, O_2{:}Object\ (Attraction\text{-}\textsc{Link}(O_1, O_2) \leftrightarrow \mathsf{forces}(O_1, O_2) \wedge \mathsf{forces}(O_2, O_1))$$

By adding this to the Force-SUPPORT image schema you find yourself in the LINKage that has primitives of CONTACT and bi-directional force, see below.

$$\forall O_1, O_2{:}Object\ (Glue\text{-}\textsc{Link}(O_1, O_2) \leftrightarrow \textsc{Contact}(O_1, O_2) \wedge Attraction\text{-}\textsc{Link}(O_1, O_2))$$

Now that the static Two-Object relation image schemas have been introduce both in terms of their family as well as in their formalisation, the next section will be devoted to some of the members of the PATH-following family.

4.4 *Formalising the* PATH *Family*

The Two-Object family looked at static object relations. The PATH family instead deals with the movement of objects (Figure 3.3 or Figure 4.7 for a smaller version). In Chapter 3, the image schema family was formalised using first-order logic to describe the ontological development between the members. As ISL^{FOL} is a language to represent the spatiotemporal dimension in image schemas, some of the members of the family will be re-formalised to follow the introduced logic.

While from an ontological point of view, there might exist scenarios in which there exists movement without any objects, this is an unintuitive notion from a cognitive perspective. This means that for all kinds of movement, at least one object is needed. Additionally, the movement needs to take place in a spatial 'region', or on a PATH. This means that for all members of the PATH family at least the spatial primitives OBJECT and PATH are present.

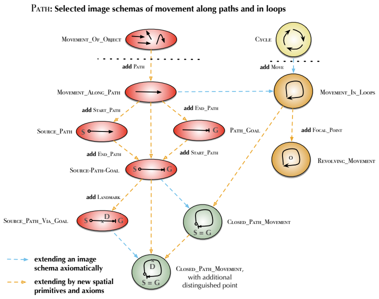

Figure 4.7: The PATH family. See Chapter 3 and Figure 3.3 for more details.

4.4.1 *Required Spatial Primitives*

While there is no physical need for the PATH to be connected to the OBJECT in order to follow the introduced logic it is presupposed that by using the described CONTACT schema, which implies 'not DC' (disconnected) from the RCC-8 calculi, it is possible to represent the dynamic image schema PATH-following using an object that proceeds to move along that path.

As movement implies a temporal dimension, the formalisation must take this into account. As discussed in the previous chapter on the different conceptualisations of SOURCE_PATH_GOAL, Mandler and Cánovas [2014] argue for there to be a conceptual primitive called 'move'. For the formalisation of movement of an object without a relative point of reference (i.e. another object or location, both discussed as early learned spatial primitives in [Mandler and Cánovas, 2014]) this spatial primitive is put to use. This is intended to be entirely purpose free movement in which an object is present at one location (L_1) and as a consequence of the movement at some point will have another location (L_2) in the future. This is a weak form of movement, as the object can move back and forth. In order to be able to use the spatial primitive Move in the remainder of the Path family it first needs to be formalised. As the logic used is two-sorted, 'paths' are differentiated from the 'objects'. Move is here defined by the relative movement to the perceiver at point *Me*.

$$\forall O{:}Object\ \big(Move(O) \leftrightarrow \\ (\exists y{:}Region\ (O \rightsquigarrow y))\big)$$

Movement_Of_Object*:* As it was argued to be unintuitive to speak of movement without objects, there is no difference in formal representation between the spatial primitive Move and the first member of the Path-family, namely Movement_Of_Object. Hence the formalisation is simplified with assuming that $\forall O{:}Object\ \big(\textsc{Movement\_Of\_Object}(O) \leftrightarrow Move(O)\big)$.

Movement_Along_Path*:* Following the branching of the family, the second step in the formalisation is to add a particular path, or trajectory that the object moves along. Just like objects are referred to as O_n the Paths are written P_n.

$$\forall O{:}Object, \forall P{:}Path\ \big(\textsc{Movement\_Along\_Path}(O,P) \leftrightarrow \\ Move(O) \wedge \textsc{Contact}(O,P)\ \mathbf{U}(\neg(Move(O) \vee \textsc{Contact}(O,P)))\big)$$

Movement_Along_Path: *O* moves in the space, while remaining in contact with the path *P*.

Source_Path *and* Path_Goal*:* As the family get more and more specific more spatial primitives are added. First speaking of only source, then of only a goal, only to add them together to create a full Source_Path_Goal structure.

$$\forall O{:}Object, \forall P{:}Path\ \big(\textsc{Source\_Path}(O,P) \leftrightarrow \\ NTTP(Source(P) \wedge O \hookleftarrow Source(P) \wedge \\ \textsc{Movement\_Along\_Path}(O,P)\big)$$

$$\forall O{:}Object, \forall P{:}Path\ \big(\textsc{Path\_Goal}(O,P) \leftrightarrow \\ NTPP(Goal(P) \wedge O \hookleftarrow Goal(P) \wedge \\ \textsc{Movement\_Along\_Path}(O,P)\big)$$

First, Source_Path is modelled in which *O* moves along *P* from *P*'s source. Second, Path_Goal is modelled with *O* moving towards a goal on *P*.

Source_Path_Goal*:* Merged together the union of these two formalisations form the most classic form of the image schema, namely Source_Path_Goal.

$$\forall O{:}Object, \forall P{:}Path\ \big(\textsc{Source\_Path\_Goal}(O,P) \leftrightarrow (Source(P) \neq Goal(P)) \wedge \textsc{Source\_Path}(O,P) \wedge \textsc{Path\_Goal}(O,P)\big)$$

Source_Path_Via_Goal: The path family becomes increasingly complex with additional segments, such as that found when Source_Path_Goal is enhanced by the addition of a middle stop/-point to pass. This means that while there is an overall goal of the movement, there is also a distinct point on the Path that needs to be reached. In the Path family, this was referred to as Source_Path_-Via_Goal.

$$\forall O{:}Object, \forall P{:}Path, \forall R{:}Region\ \big(\textsc{Source\_Path\_Via\_Goal}(O,P,R) \leftrightarrow \textsc{Source\_Path\_Goal}(O,P) \wedge DC(Source(P),R) \wedge DC(Goal(P),R) \wedge NTPP(R,P)\big)$$

Source_Path_Via_Goal is modelled as two successive Source_Path_Goal in which the middle location is initially the goal and second takes the place as the source for the movement.

Closed_Path_Movement, Movement_In_Loops and Revolve_-Around: In the case of circular movement, the Source and the Goal are simply allowed to be the same entity. This also describes scenarios in which objects move back and forth, such as objects thrown up in the air.

$$\forall O{:}Object, \forall P{:}Path\ \big(\textsc{Closed\_Path\_Movement}(O,P) \leftrightarrow (Source(P) = Goal(P)) \wedge \textsc{Source\_Path}(O,P) \wedge \textsc{Path\_Goal}(O,P)\big)$$

Closed_Path_Movement is the form of Source_Path_Goal in which the goal and the source are equal.

Closed_Path_Movement also resembles Movement_In_-Loops, with the difference that the latter does not have a defined end but continues. As ISL^{FOL} has no possibility to write continuous movement at the moment, this is not possible to express in the logic. Similar it is possible for one object to revolve around another object that it has no relative movement towards/from. As this also is a form of continuous movement, the logic (for the time being) falls short to describe these scenarios.

The Path-following family is one of the most important image schemas and there are undeniably more members than those considered and formalised in this chapter. The logic presented provides a stepping stone to how this can be approached further. In the upcoming Chapter 5 the image schemas will be combined with one another to demonstrate how this formal language can model simple events and more complicated image-schematic concepts.

4.5 *Chapter Conclusion*

This chapter introduced ISL^{FOL} which is a logical language to represent the spatiotemporal aspects of conceptual building blocks such as image schemas. Inspired by previous formalisations of image schemas (e.g. Galton [2010], Bennett and Cialone [2014]), the logic deals with the spatial dimensions through the Region Connection Calculus (RCC) together with the cardinal directions according to Ligozat [1998]. To deali with relative movement between objects and regions, the logic uses Qualitative Trajectory Calculus (QTC) which is simplified to formally represent how one object relates to another object in terms of movement. The temporal dimension of image schemas is handled with Linear Temporal Logic (LTL) as it, arguably, is enough to present the sequence of events in the image schemas.

As a proof of concept, the logic was used to formally represent the Two-Object family and the PATH family from the previous chapter 3.

In the upcoming chapter, the logic will be used to express how increasingly more complicated scenarios and simple events can be formally expressed. This is done by looking closer at what it means when different image schemas are combined with one another. For that, the dynamic aspects of CONTAINMENT are formalised as well as the simple events BLOCKAGE, CAUSED_MOVEMENT and BOUNCING.

5

Modelling Conceptualisations: Combining Image Schemas to Model Event Conceptualisations

The whole is more than the sum of its parts.

Aristotle
Metaphysica

Content and Context

The notion that image schemas are used as conceptual building blocks in language and conceptualisations as a whole has been repeatedly pushed. It was repeatedly demonstrated that the qualification for image-schematic concepts and the identification between the different image schemas are problems for the research field. Suggested was that more complex image schemas could be viewed as combinations of simpler image-schematic structures, or components from different families. This chapter explores this by looking specifically at image schema combinations. After introducing three different types of image-schematic combinations it also aims to demonstrate how these combinations can be considered to construct the conceptualisation of complex image schemas and simple events as in 'image schema profiles'. This is placed into the framework of formalising image schemas by discussing their usefulness in commonsense reasoning problems. As a proof of concept ISL^{FOL} formalisations of the dynamic aspects of Containment and the simple image-schematic events Blockage, Caused_Movement and Bouncing are included.

The chapter includes considerations and discussions on :

- Commonsense reasoning with image schemas
- Simple vs. complex image schemas
- Three types of image schema combinations
- Formalising the Dynamic Aspects of Containment
- Formalising Blockage, Caused_Movement and Bouncing

5.1 Motivation

5.1.1 Commonsense Reasoning with Image schemas

One of the reasons why it matters to look at image schemas not only from an individual instance point of view, but also what they mean for conceptualisations of events and narrative, is the potential impact it may have for commonsense reasoning problems.

For instance, in Morgenstern's [2001] solution to Davis' prototypical *Egg Cracking problem*[1], Morgenstern uses no less than 66 axioms to describe the process of cracking an egg into a bowl. In more complex scenarios, such as making an omelette or preparing pancakes, the number of needed axioms and designed knowledge increases. While artificial intelligence research has recently dramatically advanced with new technologies and methodologies concerning neural networks and machine learning, many AI systems that strive for modelling human commonsense reasoning still rely on hard-coded formal representations of basic aspects of cognition. Indeed, for humans, understanding and executing scenarios, such as egg cracking, are automatic processes, and whatever script underlies these actions, little mental effort is required. Imagine if it was possible to use some of the human automation also for artificial intelligence research.

For this combinations of image schemas as a means to express not only affordances but also to express narratives can come to play an important part. The image schemas have been repeatedly demonstrated to be an important part in analogical reasoning. For computational commonsense reasoning, this form of information transfer holds promise as it does not reject the classic knowledge representation format, and therefore allows for integration into already build systems such as the analogy engine HDTP [2] or the conceptual blender HETS [3], more on this in the upcoming Chapter 6.

5.1.2 Simple vs. Complex Image Schemas

Some important characteristics of image schemas are that they exist both as static and dynamic concepts [4,5], and both in simple and more complex form [6]. As was demonstrated in previous chapters with the identification problem, there appears to be no clear border for when one image schema ends and another begins [7]. Implying that the borders between image schemas are blurred if not directly overlapping. Simple image schemas tend to be more straightforward than complex image schemas. One major differentiation between simple and complex image schemas is that complex image schemas arguably can be described as higher level concepts within the image schema family, basically approaching the identification problem through a hierarchy

[1] See `commonsensereasoning.org/problem_page.html` for the problem description.

[2] Martin Schmidt, Ulf Krumnack, Helmar Gust, and Kai-Uwe Kühnberger. Heuristic-Driven Theory Projection: An Overview. In H. Prade and G. Richard, editors, *Computational Approaches to Analogical Reasoning: Current Trends*, volume 548 of *Computational Intelligence*. Springer, 2014b

[3] Till Mossakowski, Christian Maeder, and Klaus Lüttich. The Heterogeneous Tool Set. In Orna Grumberg and Michael Huth, editors, *TACAS 2007*, volume 4424 of *Lecture Notes in Computer Science*, pages 519–522. Springer, 2007

[4] Alan Cienki. Some properties and groupings of image schemas. In Marjolijn Verspoor, Kee Dong Lee, and Eve Sweetser, editors, *Lexical and Syntactical Constructions and the Construction of Meaning*, pages 3–15. John Benjamins Publishing Company, Philadelphia, 1997

[5] Ming-yu Tseng. Exploring image schemas as a critical concept : Toward a critical-cognitive linguistic account of image-schematic interactions. *Journal of literary semantics*, 36:135–157, 2007

[6] Jean M. Mandler and Cristóbal Pagán Cánovas. On defining image schemas. *Language and Cognition*, 6(4):510–532, May 2014

[7] Joseph E. Grady. Image schemas and perception: Refining a definition. In B. Hampe and J.E. Grady, editors, *From Perception to Meaning: Image Schemas in Cognitive Linguistics*, pages 35–55. Mouton de Gruyter, Berlin, 2005

of increasing complexity. However, for this to be possible, complex image schemas often inherit spatial primitives from other image-schematic families [8], turning them into combinations of different image schemas. For instance, Lakoff and Núñez [2000] demonstrate how the combination of CONTAINMENT and SOURCE_PATH_GOAL forms the conceptual structure in prepositions and verbs such as 'into' and 'entering', which naturally transfer to more complex natural language expressions such as 'to get into trouble'. Likewise, take the spatiotemporal events of 'pouring coffee into a cup' or 'going into the house', both of these scenarios are traditionally considered to be part of the CONTAINMENT schema through the subcategory of the IN schema. In Section 5.3 this will be further analysed as the dynamic aspects of CONTAINMENT will be formally unravelled.

5.2 *Image Schema Combinations*

It is clear that image schemas can be combined with one another in many different ways. In order to pinpoint the nature of image schema combinations, a few examples will be provided. First, the combination between the image schemas LINK and PATH into a new image-schematic structure: LINKED_PATH, appears as cognitively intuitive. It follows from how easy it is to visualise two objects that move together and react to external stimuli in the same way (or through transitivity). The conceptual blend that takes place in the merge follows naturally. Based on the information transfer that underlay image schemas, this combination is also used as a means to explain abstract concepts. A real life example is the conceptualisation of the concept 'marriage', where two individuals are perceived to go through life together [9].

Similarly, PATH can be combined with SUPPORT (or CONTAINMENT), resulting in the conceptualisation behind 'transportation' [10]. This is particularly interesting because it illustrates how image schemas become part of the definition of what concepts are[11].

Another metaphorical example is the idiom 'to hit the wall'. In many contexts, this does not mean to physically crash into a wall but instead implies some form of mental breakdown, often preceded by long-term stress or exhausting efforts. The idiom captures the image schema of BLOCKAGE. It is clear that BLOCKAGE is not an atomic image schema but rather a temporal combination of several ones. Breaking it down, there are at least two OBJECTS, at least one member of the PATH-family, and at least one time point when the two objects are in CONTACT. Translating it to the linguistic expression: The OBJECTS represent the person and the abstract time point and/or scenario with which the person 'crashed', so to speak, and this mo-

[8] Francisco Santibáñez. The object image-schema and other dependent schemas. *Atlantis*, 24(2):183–201, 2002

[9] Jean M. Mandler. *The Foundations of Mind: Origins of Conceptual Thought: Origins of Conceptual Though*. Oxford University Press, New York, 2004

[10] Werner Kuhn. An Image-Schematic Account of Spatial Categories. In Stephan Winter, Matt Duckham, Lars Kulik, and Ben Kuipers, editors, *Spatial Information Theory*, volume 4736 of *Lecture Notes in Computer Science*, pages 152–168. Springer, 2007

[11] This as an idea was empirically investigated and the results are presented in Chapter 7.

ment captures an abstract version of the image schema Contact. Additionally, as was previously demonstrated, Paths often describe time and processes. In this case, the Path present in the idiom captures the time and processes that precede the 'crash'.

As demonstrated, this kind of image-schematic breakdown can be done not only on concrete scenarios but also on many abstract natural language expressions. These mentioned examples lead to primarily three different ways in which image schemas can be combined with one another. These three methods are introduced and discussed under the names: *Merging*, *collection* and *sequence* (see Figure 5.1).

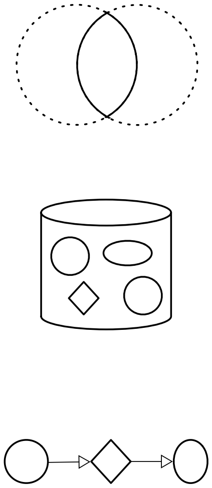

Figure 5.1: Illustration of the three different types for how image schemas can be combined with one another.

5.2.1 The Three Different Types of Image Schema Combinations

Merging: Occurs when two image schemas are combined in such a way that the Gestalt laws are altered. This is the case with Linked_Path, which is a conceptual merge of two image-schematic notions. It would correspond to the intersections in the image schema families in which multiple families are contributing with image-schematic components.

Collection: A collection of image schemas do not per se alter the Gestalt properties of a particular spatiotemporal relationship, but instead functions as a joint representation for a particular concept. Most representations of concepts and non-linear events fit into this category. A previously mentioned example is the conceptualisation of 'transportation' as the combination of Path and Support and/or Containment.

Sequence: This represent the image-schematic conceptualisations that behave much like *collection*, only with the addition of a sequential dimension. This means that sequence combinations most often conceptualise processes and events (usually with a clear linear structure) rather than static concepts. In the upcoming sections, this will be looked at in the cases of formalisation of Blockage, Caused_Movement and Bouncing[12].

5.2.2 Defining Events

Throughout this chapter, events are to be understood as defined, for instance, by Galton [2012] who defines an event "(...) is a temporally bounded occurrence typically involving one or more material participants undergoing motion or change, usually with the result that at least one partipant [sic!] is in a different state at the end of the event from the beginning".[13] This notion of event is also well-suited to an embedding in the context of narratives (which are to be understood as reports of connected events presented in a sequential manner as

[12] Note that Bouncing has not been introduced as an image schema despite its image-schematic event structure.

[13] The precise ontological nature and status of events has for a long time been, and still is, an open question and lies outside the focus of the present article. The reader may look closer at, for instance, Bach [1986] for a classic account on the classification of events and their internal structure. Alternative proposals have also been made by Mourelatos [1981], Pustejovsky et al. [2005], Lambalgen and Hamm [2005], among others.

mental images, written or spoken words, visual scenes, and/or similar), particularly when allowing for participants that only exhibit a 'derived materiality'.

The next sections will demonstrate how a few complex image schemas and simple events can emerge as consequences of combinations of simpler image schemas. These combinations will build on the family representation in Chapter 3 and the logic presented in Chapter 4. First the dynamic aspects of CONTAINMENT are introduced, as they represent good examples of image schemas merging together, followed by the somewhat more complex scenarios BLOCKAGE, CAUSED_MOVEMENT and BOUNCING, which represent a sequential combination of image schemas (Collections of image schemas will be empirically investigated in Chapter 7).

5.3 *Formally Modelling the Dynamic Aspects of* CONTAINMENT

5.3.1 *Requirements of* CONTAINMENT

Objects, Containers and Openings

While image schemas can often be described without direct reference to objects, it might be seen as unintuitive to speak of spatiotemporal relationships without considering the spatial primitive OBJECT [14]. For CONTAINMENT, a minimum of two objects is required: a container and a containee. In the context of the logic described above, it is the atomic names O_i that represent objects (here: considered subsets of 3D Euclidean space). Given the lack of restrictions on the interpretations of the O_i, these objects can also cover the 'openings' of containers or other, not strictly physical interpretations of objects. Only finitely many objects (actually rarely more than 3 or 4) participate in a given scenario, and therefore direct quantification over objects is intentionally avoided with the motivation that it is cognitively inadequate.

The kinds of entities that are clearly relevant from an image-schematic point of view on CONTAINMENT are: (i) (physical) objects, (ii) insides and outsides (of objects), (iii) openings (of objects), and (iv) paths ('carrying' the movement of objects). These need not be analysed further topologically, and therefore the language is augmented with the following primitive predicates:

- $\mathsf{inside}(O)$: is a function to denote the *inside* of O
- $\mathsf{opening\_of}(op, O)$: op is an opening of O,
- $\mathsf{cavity\_of}(cav, O)$: cav is a cavity of O

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[14] Jean M. Mandler and Cristóbal Pagán Cánovas. On defining image schemas. *Language and Cognition*, 6(4):510–532, May 2014

Here, it is supposed that all objects may only have one $\text{inside}(I)$, but they may have several openings $\text{opening\_of}(op, O)$ and cavities $\text{cavity\_of}(cav, O)$. Imagine for example a cabinet, it usually has several drawers each with its own hatch, yet objects are inside the cabinet regardless of in which drawer they are. A bowl on the other hand has only one inside with one cavity, but in some cases the borders of the 'inside' can extend outside of the physical borders. For instance, in an overflowing fruit bowl, even the apples that are 'outside' of the container are still inside the bowl. Here the inside is larger than the bowl's cavity. Rather than further analysing these predicates topologically, they are assumed to be fixed by the model, with appropriate interpretation functions. Solutions for defining these notions in detail can be found in the literature [15,16], and are omitted here to focus on the high-level commonsense modelling of the dynamics of containment. Notice that an opening can be both an object, or a path, and vice versa, therefore no restrictions on the interpretations are meaningful in general. Further, as evidenced by examples such as "And he said, Call her. And when he had called her, she stood in the door" [17], or an expression like 'He got stuck in the revolving door', openings can be containers of objects at the same time.

Three different kinds of containers, then, can be distinguished regarding the role of openings. While all types of containers per definition have an inside, an outside and a border [18], these kinds can be differentiated by the nature of the realisable dynamic aspects, namely how objects can move In and Out of them.

This means that the border's characteristics are highly relevant for the dynamic aspects of Containment insofar as they relate to openings, just as the characteristics of the containee and the container are essential to the nature of the static representation of Containment (e.g. a contained liquid is more likely to correspond to a tight-fitted container). However, from an image-schematic point of view, it is the affordance-centred characteristics of openings regarding possible movements, rather than the mereotopological analysis of the border, which is central to the basic understanding of the dynamics of containers.

One opening: These are the most prototypical containers, in which objects go in and out through the same entry point. A coffee cup fits this category.

Two or more openings: These are the containers in which object may exit at another point than the entry. Tunnels, buildings and colanders belong to this category.

Flexible openings: These containers have 'liquid' borders in which

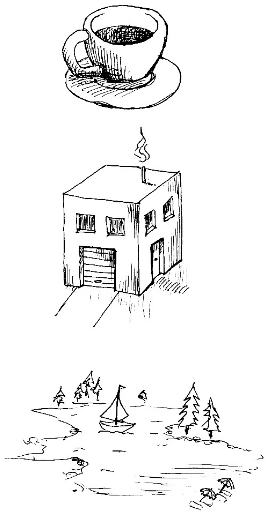

Figure 5.2: The three different kinds of containers considered: a cup, a building and a lake.

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[15] Ernest Davis, Gary Marcus, and Noah Frazier-Logue. Commonsense reasoning about containers using radically incomplete information. *Artificial Intelligence*, 248:46–84, 2017

[16] Roberto Casati and Achille C. Varzi. *Spatial Entities*, pages 73–96. Springer, Dordrecht, 1997

[17] 2 Kings 4:15, King James Bible

[18] Mark Johnson. *The Body in the Mind: The Bodily Basis of Meaning, Imagination, and Reason*. University of Chicago Press, 1987

no directly specified openings exist, but where objects can (essentially) leave the containment through any part of the border. Spatial regions, liquids and more abstract concepts are examples of this kind of container.

While an opening is arguably most often part of the object's border (when understood in the commonsense meaning of the word rather than topologically), which in turn can be argued to be part of the conceptualisation of a container[19], any opening has two potential states. The opening may either be bi-directional, as in a cup in which coffee can both go in an out, or uni-directional in which objects can only move in one direction (or simply only move through once) such as normally found when eating and swallowing.

Representation of Static CONTAINMENT

Despite distinguishing between three different kinds of containers in relation to their openings, the nature of the actual containment, such as the eight found CONTAINMENT relationships presented in [Bennett and Cialone, 2014], is not considered. Simplified, it is presupposed that if something is contained within another object, it does not (at the moment) matter if they touch the border or not, whether they are tight (NTPP) or loose (TPP) forms of CONTAINMENT. Following the ISL^{FOL} language in Chapter 4, the formalisation of the state of one object being contained within another by first establishing the relationship of a proper part (PP):

$$\forall x, y{:}Region\ \big(PP(x,y) \leftrightarrow TPP(x,y) \vee NTPP(x,y)\big)$$

$$\forall O_1, O_2{:}Object\ (\text{Contained\_Inside}(O_1, O_2) \leftrightarrow PP(O_1, \mathsf{inside}(O_2)))$$

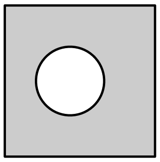

Figure 5.3: Illustration of Contained_Inside(x,y)

As it is possible also for objects to be inside regions and for regions to be inside objects two additional versions are needed:

$$\forall O{:}Object, \forall R : Region\ (\text{Contained\_Inside\_}Region(O,R) \leftrightarrow PP(O, \mathsf{inside}(R)))$$

And analogous:

$$\forall O{:}Object, \forall R : Region\ (Region\text{\_Contained\_Inside}(R,O) \leftrightarrow PP(R, \mathsf{inside}(O)))$$

[19] In cases like a fruit bowl it may be unclear where this border actually goes. No attempts to solve this topological issue is made, but it is assumed that at some point the apple simply is 'within' the container's border and, thus, contained in the bowl. A typical mereotopological analysis for this would use the notion of 'enclosure' [Casati and Varzi, 1997], perhaps elaborated by adding 'convexity' into the modelling [Haemmerli and Varzi, 2014].

Next, as a first approximation, the outside is defined as the complement of the object together with its inside, based on assumed Boolean region terms, as studied in the case of RCC8 in detail in [Wolter and Zakharyaschev, 2000].

$$\forall O_1, O_2{:}Object\ \big(\mathsf{outside\_of}(O_1, O_2) \leftrightarrow \\ DC(O_1, \mathsf{inside}(O_2)) \vee EC(O_1, \mathsf{inside}(O_2))\big)$$

Related Object Movement

After introducing the state of being contained, one of the central foci is how to represent relative movement between the containee to-be and the container. While the SOURCE_PATH_GOAL schema was thoroughly introduced in Chapter 3, for this purpose the movement dimension is simplified by talking exclusively of relative object movement following the ISL^{FOL} language. This is represented in the following manner:

$$\forall O_1, O_2{:}Object\ \big(\text{On\_PATH\_Toward}(O_1, O_2) \leftrightarrow \\ (O_1 \rightsquigarrow O_2 \wedge \mathsf{outside\_of}(O_1, O_2))\big)$$

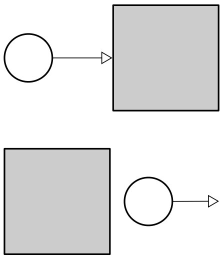

Figure 5.4: Illustration of $x \rightsquigarrow y$ respective $x \hookleftarrow y$

As with Contained_Inside above, two additional formalisations are needed to take into account when objects are moving towards regions, respective when regions are moving towards objects.

Note that in the case that the objects are externally connected (EC) the distance between the objects needs to be calculated based on the geometric centre, rather than the shortest possible distance.

$$\forall O{:}Object, \forall R{:}Region\ (\text{On\_PATH\_From\_}Region(O, R) \leftrightarrow \\ (O \hookleftarrow R \wedge \mathsf{outside\_of}(O, R)))$$

$$\forall O{:}Object, \forall R{:}Region\ (Region\text{\_On\_PATH\_Toward}(R, O) \leftrightarrow \\ (R \rightsquigarrow O \wedge \mathsf{outside\_of}(R, O)))$$

Enforced by the entailments of image schemas, transitivity is an essential aspect of not only the static aspects but also the dynamic aspects of CONTAINMENT [20]. This means that if the container moves, the containee must move as well. This is true for all 'true containers'[21] namely that:

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[20] Mark Johnson. *The Body in the Mind: The Bodily Basis of Meaning, Imagination, and Reason*. University of Chicago Press, 1987

[21] In opposition, a non-true container would not entail this transitivity and could for example simply denote 'overlap'. For example, 'being in the shade' would demonstrate a non-true container.

$$\forall O_1, O_2, O_3{:}Object\ ((\text{Contained\_Inside}(O_1, O_2) \land \text{On\_Path\_From}(O_2, O_3)) \implies \text{On\_Path\_From}(O_1, O_3))$$

Entering the Opening

Dynamic aspects of image schemas can be dissected into smaller building blocks. First, is the scenario of one object entering the container's opening, or 'crossing its border'. To avoid temporal confusion, the formalisations assume continuity of time and space and therefore omit some of the logical steps of the sequence in order to better model human cognition following the results in [Bogaert et al., 2008].

Simplified, one can argue that an object is contained as long as it has entered the container, and not left it. The formalisation below can easily be translated to crossing the border by substituting the opening for a border. Formalised it reads:

$$\forall O_1, O_2{:}Object, \forall op{:}Region\ \big(\text{Crossing\_Opening}(O_1, O_2, op) \leftrightarrow \text{opening\_of}(op, O_2)\ \land (\text{On\_Path\_Toward}(O_1, op)\ \mathbf{U}\ PO(O_1, op))\big)$$

In this variation, it is the opening of object O_2 that is doing the moving.

$$\forall O_1, O_2{:}Object, \forall op{:}Region\ \big(\text{Opening\_Crossing}(O_1, O_2, op) \leftrightarrow \text{outside\_of}(O_1, O_2) \land \text{opening\_of}(op, O_2)\ \land (\text{On\_Path\_Toward}(op, O_1)\ \mathbf{U}\ PO(O_1, op))\big)$$

Now that these formal building blocks are introduced, let us proceed to see what the three of the most basic dynamic aspects of CONTAINMENT look like: *going* IN, *going* OUT and *going* THROUGH.

5.3.2 *Dynamics of* CONTAINMENT

Going IN: The most obvious dynamic aspects of CONTAINMENT are the movements of entering and exiting. As it has already been formalised what crossing the opening looks like, the difference lies in the end state. Entry/going into:

$$\begin{aligned}\forall O_1, O_2{:}Object, \forall op{:}Region\ \big(\mathit{Going\_}\textsc{In}(O_1, O_2, op) \leftrightarrow&\\ \text{On\_}\textsc{Path}\text{\_Toward}(O_1, op)&\\ \mathbf{U}\ PO(O_1, op)&\\ \mathbf{U}\ \text{Contained\_Inside}(O_1, O_2)\big)&\end{aligned}$$

There is also the scenario in which it is the container that takes the active role in 'something becoming contained'. Here it is presented as 'Swallowed_By' to illustrate the active role of the container:

$$\begin{aligned}\forall O_1, O_2{:}Object, \forall op{:}Region\ \big(\mathit{Swallowed\_By}(O_1, O_2, op) \leftrightarrow&\\ (\mathsf{outside\_of}(O_1, O_2) \wedge \text{On\_}\textsc{Path}\text{\_Toward}(O_2, O_1))&\\ \mathbf{U}\ \text{On\_}\textsc{Path}\text{\_Toward}(op, EO_1)&\\ \mathbf{U}\ PO(O_1, op)&\\ \mathbf{U}\ \text{Contained\_Inside}(O_1, O_2))\big)&\end{aligned}$$

Going OUT: Similarly, there are two forms of exit. One dominated by the containee and one by the container. The second scenario is particularly interesting as it implies a weakened LINK-state between the containee and the container, as the container 'leaves' or ejects the containee behind. Previously it was pointed out that these are not necessarily 'true containers', but regardless humans still use similar linguistic expressions for them.

$$\begin{aligned}\forall O_1, O_2{:}Object, \forall op{:}Region\ \big(\mathit{Going\_}\textsc{Out}(O_1, O_2, op) \leftrightarrow&\\ \text{Contained\_Inside}(O_1, O_2)&\\ \mathbf{U}\ \text{On\_}\textsc{Path}\text{\_Toward}(O_2, O_1))&\\ \mathbf{U}\ PO(op, O_1)&\\ \mathbf{U}\ \mathsf{outside\_of}(O_1, O_2)\big)&\end{aligned}$$

When the container moves away from the containee[22]:

$$\begin{aligned}\forall O_1, O_2{:}Object, \forall op{:}Region\ \big(\mathit{Container\_Leaving}(O_1, O_2, op) \leftrightarrow&\\ \text{Contained\_Inside}(O_1, O_2)\wedge&\\ \mathbf{U}\ \text{On\_}\textsc{Path}\text{\_Toward}(O_2, O_1))&\\ \mathbf{U}\ PO(op, O_1)&\\ \mathbf{U}\ \mathsf{outside\_of}(O_1, O_2))\big)&\end{aligned}$$

Going THROUGH: In Section 5.3.1, three different kinds of containers where distinguished, based on their number of openings. Naturally,

[22] In the case of actual 'ejection of the containee', a formal representation of force and agency is needed.

in order to go THROUGH something, one cannot exit at the entry point. It is therefore essential to not only go IN and OUT, but to go out at another location, basically following the idea that "when a door closes, a window opens". Thus, the two openings are part of the conceptualisation of 'going THROUGH':

$$\begin{aligned}\forall O_1, O_2{:}\mathit{Object}, \forall op_1, op_2{:}\mathit{Region}\ \big(\mathit{Going\_}\textsc{Through}(O_1, O_2, op_1, op_2) \leftrightarrow\\ \textsf{opening\_of}(op_1, O_2) \wedge \textsf{opening\_of}(op_2, O_2)\ \wedge (op_1 \neq op_2) \wedge\\ (\mathit{Going\_}\textsc{In}(O_1, O_2, op_1)\\ \mathbf{U}\ \text{Contained\_Inside}(O_1, O_2)\\ \mathbf{U}\ \mathit{Going\_}\textsc{Out}(O_1, O_2, op_2)\\ \mathbf{U}\ (\textsf{outside\_of}(O_1, O_2))\big)\end{aligned}$$

The dynamic aspects of CONTAINMENT are only one of the areas in which combinations of image schemas can be formalised. In the next section, this will be extended upon by formalising the conceptualisation of events.

5.4 *Formally Modelling* BLOCKAGE, CAUSED_MOVEMENT *and* BOUNCING

In order to explain how image schema combinations model events, the PATH family will be combined with the Two-Object Family to model the complex image schemas BLOCKAGE and CAUSED_MOVEMENT as well as the conceptually similar event BOUNCING.

5.4.1 *Formalising* BLOCKAGE

BLOCKAGE, or 'blocked movement', is a commonly mentioned image schema in the literature as children early learn to predict how one object may hinder the movement of another. This is a common phenomenon that may have many different outcomes and in the following sections, (some of) these outcomes will be explored. Needed first, however, is the most general form of BLOCKAGE.

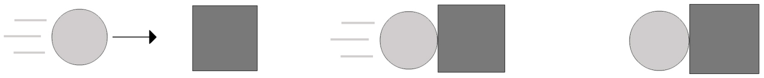

(a) Stage one (b) Stage two (c) Stage three

Figure 5.5: Illustrations of the three time intervals of BLOCKAGE. a) O_1 On_PATH_TowardO_2. b) O_1 Blocked_By O_2. c) O_1 In_CONTACTwith O_2.

The simplest form of blocked movement is the scenario in which the movement of an object simply ceases to exist. While BLOCKAGE is consider an image schema in its own right, it is also possible to describe blockage using a sequential series of simple image schemas:

Movement_Of_Object, Contact and ‘force’[23], followed by the lack of Movement_Of_Object. Figure 5.5 illustrate these three image-schematic stages.

Following the formalisation language ISL^{FOL} that was introduced in Chapter 4 these three stages demonstrated in Figure 5.5 can individually be represented as[24]:

$$\forall O_1, O_2{:}Object\ \big(\text{On\_}\textsc{Path}\text{\_Toward}(O_1, O_2) \leftrightarrow \\ O_1 \rightsquigarrow O_2 \wedge \mathsf{outside\_of}(O_1, O_2)\big)$$

$$\forall O_1, O_2{:}Object\ \big(\text{Blocked\_By}(O_1, O_2) \leftrightarrow \\ (O_1 \mid\circ\, O_2 \wedge O_2 \mid\circ\, O_1 \wedge Force\text{-}\textsc{Support}(O_1, O_2))\big)$$

$$\forall O_1, O_2{:}Object\ \big(\textsc{Contact}(O_1, O_2) \leftrightarrow \\ (O_1 \mid\circ\, O_2 \wedge O_2 \mid\circ\, O_1 \wedge EC(O_2, O_1))\big)$$

(a) O_1 On_Path_Towardtoward O_2. (b) O_1 Blocked_ByO_2. (c) O_1 in Contact with O_2.

Using these building blocks to model the temporal scenario of Blockage with the ISL^{FOL} results in the following formalisation[25]:

$$\forall O_1, O_2{:}Object\ \big(\textsc{Blockage}(O_1, O_2) \leftrightarrow \\ (\text{On\_}\textsc{Path}\text{\_Toward}(O_1, O_2)\ \mathbf{U}\ \text{Blocked\_By}(O_1, O_2) \\ \mathbf{U}\ \text{In\_}\textsc{Contact}(O_1, O_2))\big)$$

Here, the time operator guarantees that these events happen in the correct temporal order.[26]

As these first steps until contact between two objects happen reoccur for all the subsequent scenarios, the defined predicates of On_Path_Toward(O_1, O_2) and Blocked_By(O_1, O_2) will be repeatedly put to use.

One interesting thing to note here is that formalised and in combination with motion, Blockage works much like Force-Support. Compare the axiom for Support and the axiom for Blocked_By (see Margin). The only difference is the addition of a temporal aspect through the lack of movement ($O_1 \mid\circ\, O_2 \wedge O_2 \mid\circ\, O_1$). This is an interesting observation, as our experience is effected by our physical world, meaning that gravitational pull could be viewed as a sort of ‘downward’ movement and that all Support is simply Blockage of movement in that direction. In an alternative universe with different physical laws, either through science fiction or artificial simulation, it is likely that there would be other distinctions for these image schema structures.

$$\forall O_1, O_2{:}Object\ \big(Force\text{-}\textsc{Support}(O_1, O_2) \leftrightarrow \\ EC(O_1, O_2) \wedge \mathsf{forces}(O_1, O_2)\big)$$

$$\forall O_1, O_2{:}Object\ \big(\text{Blocked\_By}(O_1, O_2) \leftrightarrow \\ (O_1 \mid\circ\, O_2 \wedge O_2 \mid\circ\, O_1 \wedge \\ Force\text{-}\textsc{Support}(O_1, O_2))\big)$$

[23] In Chapter 3, force is introduced as a conceptual primitive from the force group of image schemas, more specifically, the Attraction image schema. However, it can also be described as a non-spatial component that should not be included under image schemas [Mandler and Cánovas, 2014]. Regardless, as it is not in itself an image schema it is presented in lower case letters.

[24] Note that the formalisation of On_Path_Toward(O_1, O_2) differ from that above, as it now is no longer relevant to speak of ‘insides’ and ‘outsides’. Instead the RCC relation DC is implied in the semantics.

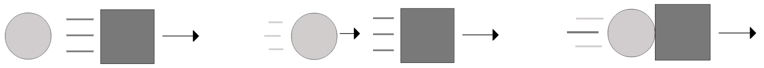
[25] Note that the semantics of ISL^{FOL} includes QTC which presuppose disjoint objects. Therefore, all representations need to take this into account.

[26] In the case of animated objects, this would behave differently.

5.4.2 *Formalising* Caused_Movement

There are more scenarios that can follow from Blockage than the static relation of Contact between the moving object and the blocking object, that was presented above. One of the more 'complex' image schemas that appear in the literature is Caused_Movement. Namely the spatiotemporal relationship that comes to be as one object crashes into another and causes the first object to move.

Simplified, this particular image schema comes in three different forms. First, in the scenario in which the hitting object comes to rest while the hit object continues onward (e.g. as in a well executed billiards chock), referred to as 'Pure_CM'. Second, in which both objects continue in disjoint forward movement, 'Pursuit_CM'. Thirdly, in the scenario in which the object together continue forward, 'Joint_CM'. This scenario holds an important distinction from the other Caused_Movements. The reason for this is that there are limited natural scenarios in which an inanimate object will proceed to push another object. What children early learn to distinguish is the role agency has in objects (including animals and people) and how this effects the movement pattern of the object. For instance, children learn how distinguish between Self_Movement and Caused_Movement at an early age and associate Self_Movement with agency and animated life. In the case of pushing, there is an underlying understanding that the first object has some power to maintain the force and direction throughout the action of the pushing which could be considered to be a sign for agency, here referred to as the conceptually weaker 'Joint_Caused_Movement' (Joint_CM).



(a) Pure_CM (b) Pursuit_CM (c) Joint_CM

Figure 5.6: Illustrations of the three alternative endings of Caused_Movement. a) O_2 move away from O_1. b) O_1 and O_2 move forward. c) O_1 and O_2 move together.

As focus lies on the second object, it is for the image schema itself irrelevant whether the first object is in movement or not. However, for the sake of completeness, all three scenarios will be individually formalised to pinpoint the complexity of properly formalising the minor differences that exist in simple events and image-schematic structures.

As presented above, the first two steps which will be consistently repeated are defined as follows first that O_1 is on a path toward O_2 which is then followed by O_1 being blocked by O_2. The first of the three alternative endings of Caused_Movement, Pure_CM (see Figure 5.6a)) is formalised below:

(a) O_2 moves away from O_1, O_1 is at rest in respect of O_2.

$$\forall O_1, O_2{:}\mathit{Object}\ (\text{Pure\_CM}(O_1, O_2) \leftrightarrow O_2 \hookleftarrow O_1 \wedge O_1 \mid\circ\, O_2)$$

The second of the three alternative endings of Caused_Movement, Pursuit_CM, (see Figure 5.6b) differs from Pure_CM as both objects move forward:

$$\forall O_1, O_2{:}\mathit{Object}\ (\text{Pursuit\_CM}(O_1, O_2) \leftrightarrow O_1 \rightsquigarrow O_2 \wedge O_2 \hookleftarrow O_1)$$

(b) O_1 moves towards O_2 which moves away from O_1.

The third alternative ending for Caused_Movement Alternative three, Joint_CM, both objects move forward while in Contact (see Figure 5.6c):

$$\forall O_1, O_2{:}\mathit{Object}\ \big(\text{Joint\_CM}(O_1, O_2) \leftrightarrow \\ \mathit{Force}\text{-}\textsc{Support}(O_1, O_2) \wedge O_1 \rightsquigarrow O_2 \wedge O_2 \mid\circ\, O_1\big)$$

(c) O_1 and O_2 in forced contact, O_1 moves towards O_2, O_2 at rest in respect to O_1. Note here that for this to be possible, the distance between the objects needs to be calculated based on the geometric centre (see Chapter 4 for more details).

These three scenarios are the most obvious scenarios that are involved in Caused_Movement. In full temporal representation, the scenarios looks as follows:

$$\begin{aligned} \forall O_1, O_2{:}\mathit{Object}\ \big(\textsc{Caused\_Movement}(O_1, O_2) \leftrightarrow \\ \text{On\_}\textsc{Path}\text{\_Toward}(O_1, O_2) \\ \mathbf{U}\ \text{Blocked\_By}(O_1, O_2) \\ \mathbf{U}\ (\text{Pure\_CM}(O_1, O_2) \veebar \text{Pursuit\_CM}(O_1, O_2) \veebar \text{Joint\_CM}(O_1, O_2))\big) \end{aligned}$$

It is here noteworthy that is it possible that the movement of O_2 is in fact not a Caused_Movement. It could be Self_Movement that simply by coincidence happened at the same time as another object was blocked by it.

5.4.3 *Formalising* Bouncing

Another natural scenario that happens as one object hits another, is Bouncing. In comparison to Caused_Movement, the object of interest here is not the object that is hit but rather the object that is doing the hitting.

The formalisation below correspond to the end result of Bounces, as depicted in Figure 5.7a.

$$\forall O_1, O_2{:}\mathit{Object}\ \big(\textsc{Bounces}(O_1, O_2) \leftrightarrow O_1 \hookleftarrow O_2 \wedge O_2 \mid\circ\, O_1\big)$$

O_1 on Path from O_2 which is at rest in respect of O_1.

In full temporal representation the scenario looks as follows:

$$\begin{aligned} \forall O_1, O_2{:}\mathit{Object}\ \big(\textsc{Bouncing}(O_1, O_2) \leftrightarrow \\ \text{On\_}\textsc{Path}\text{\_Toward}(O_1, O_2) \\ \mathbf{U}\ \text{Blocked\_By}(O_1, O_2) \\ \mathbf{U}\ \textsc{Bounces}(O_1, O_2)\big) \end{aligned}$$

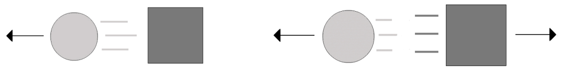
Bouncing represented using ISL^{FOL}.

5.4.4 *The Combination of* Caused_Movement *and* Bouncing

Another event that might take place is the scenario in which Caused_Movement is merged with the event of Bouncing. In this scenario, the hitting object O_1 bounces on O_2 while at the same time the impact pushes the blocking object away. Formalised the end result reads (see Figure 5.7b):

$$\forall O_1, O_2{:}\mathit{Object}\ (\text{Bouncing\_CM}(O_1, O_2) \leftrightarrow O_1 \hookleftarrow O_2 \land O_2 \hookleftarrow O_1)$$

O_1 and O_2 are on Paths away from each other.



(a) Bouncing (b) Bouncing and Caused_Movement

Figure 5.7: Illustrations of the results of Bouncing respective the result of the combination of Caused_Movement and Bouncing. a) O_1 Bounces on O_2. b) O_1 Bounces and O_2 moves forward.

The full event is then formalised as follows:

$$\begin{aligned} \forall O_1, O_2{:}\mathit{Object}\ \big(\mathit{Bouncing\_CM}(O_1, O_2) \leftrightarrow \\ \text{On\_}\textsc{Path}\text{\_Toward}(O_1, O_2) \\ \mathbf{U}\ \text{Blocked\_By}(O_1, O_2) \\ \mathbf{U}\ \text{Bouncing\_CM}(O_1, O_2)\big) \end{aligned}$$

Bouncing_CM represented using ISL^{FOL}.

5.5 *Chapter Conclusion*

It is non-trivival to represent events, not only from the perspective of developmental psychology, but also for cognitive systems and natural language comprehension in computational systems. Following the presented approach on image schemas as the conceptual building blocks, this chapter showed how the ISL^{FOL} language introduced in Chapter 4 can be used to represent not only the image schema families from Chapter 3, but can also be used to model complex image schemas, events and image schema profiles.

In the introduction of the Chapter, Morgenstern's [2001] solution to Ernie Davis's [1997] *Egg Cracking problem* was mentioned as an example to demonstrate the difficulty to formally capture a real life scenario relating to some of the Containment aspects. For egg cracking some immediate Containment notions are: how the egg is inside the shell, how it is 'poured' Out from the crack and Into the bowl. While further work is needed to validate to which extent the integration of formalised image schemas can reduce the required number of axioms as well as making better inferences in commonsense reasoning problems, the idea behind image-schematic formalisation is, in their role as conceptual building blocks, to use them as design patterns when describing scenarios and events [27].

The approach in this chapter represents some of the initial steps towards a more substantial formalisation of image schemas that can be used not only in representation of commonsense problems, but also in analogy engines (e.g. HDTP [28]) and similar systems such as those for conceptual blending (e.g. Hets [29] as demonstrated by Neuhaus et al. [2014], Gómez-Ramírez [2015]). The next chapter will particularly look at the role image schemas could play in computational conceptual blending.

[27] Tarek R. Besold, Maria M. Hedblom, and Oliver Kutz. A narrative in three acts: Using combinations of image schemas to model events. *Biologically Inspired Cognitive Architectures*, 19: 10–20, 2017b; and Robert St. Amant, Clayton T. Morrison, Yu-Han Chang, Paul R. Cohen, and Carole Beal. An image schema language. In *International Conference on Cognitive Modeling (ICCM)*, pages 292–297, 2006

[28] Martin Schmidt, Ulf Krumnack, Helmar Gust, and Kai-Uwe Kühnberger. Heuristic-Driven Theory Projection: An Overview. In H. Prade and G. Richard, editors, *Computational Approaches to Analogical Reasoning: Current Trends*, volume 548 of *Computational Intelligence*, pages 163–194. Springer, 2014a

[29] Till Mossakowski, Christian Maeder, and Klaus Lüttich. The Heterogeneous Tool Set. In Orna Grumberg and Michael Huth, editors, *TACAS 2007*, volume 4424 of *Lecture Notes in Computer Science*, pages 519–522. Springer, 2007

6

Generating Concepts: How Image Schemas Can Help Guide Computational Conceptual Blending

> Like art, revolutions come from combining what exists into what has never existed before.
>
> Gloria Steinem
> *Moving Beyond Words, 1994*

Content and Context

In the previous chapters, the formal aspects of representing image schemas were dealt with. Likewise, the role of image schemas in conceptualisations was investigated in the previous chapter. This chapter advances the work on concept invention by suggesting how image schemas can be integrated into conceptual blending, introduced in Chapter 1 as a theoretical framework for creativity. It includes two different approaches. The first focuses on giving image-schematic information higher priority to be inherited into the blended space. The second is to use image schemas as the foundation in the generic space. In addition to providing a series of examples of how this would look, the chapter also goes into details on how the family structure from Chapter 3 can be used during the blending to either strengthen or weaken the image-schematic structure in the input spaces, if needed.

The chapter includes considerations and discussion on:

- Problems with computational blending
- Previous work on formalising conceptual blending
- Using image schemas in conceptual blending: i) As priority heuristics, ii) In the generic space, iii) Blending with the family hierarchy
- Examples of image schemas in conceptual blending

6.1 Image-Schematic Information Skeletons

6.1.1 Hypotheses and Motivation

One of the main research assumptions is that image schemas construe the smallest building blocks that are used by humans to understand their world, comprehend linguistic expressions, including abstract expressions such as metaphors and event conceptualisation, as well as that they provide an information skeleton upon which analogical reasoning can be performed. In the previous chapters, some theoretical work was presented that aims to strengthen these hypotheses.

Based on these results, another hypothesis follows, namely, that if it is through image-schematic skeletons that humans gain knowledge from analogical transfer, it follows as a natural consequence that image schemas ought to play a central role in the generation of new concepts as well [1].

In Chapter 1, conceptual blending was introduced as a framework for concept invention, in which conceptual spaces, or in formal domains ontologies, are merged together under certain criteria to generate novel concepts and conceptual spaces. As image schemas represent building blocks, this chapter will discuss how image schemas can be integrated into conceptual blending and consequently also provide a useful tool for computational creativity [2,3].

Before introducing the different ways image schemas can be used in conceptual blending, some linguistic motivation is presented. This is followed by a brief introduction to the utilised formal framework for computational conceptual blending [4,5,6] set in the context of the similar computational frameworks found in analogy engines.

6.1.2 *Examples of Image Schemas as Analogy and Blending Skeletons*

In Chapter 2 image schemas were discussed in their role in conceptual metaphors and analogical reasoning. Here one suggestion was that image schemas could play a central role in the invariance principle. It states that the information transfer in all analogies is built on structure similarity. In this section, this will be linguistically demonstrated.

One of the most focused-on image schemas is the SOURCE_PATH_GOAL schema, or as it was presented in Chapter 3, the PATH family. To demonstrate how SOURCE_PATH_GOAL often constructs the conceptual skeleton, this section looks closer at how time and processes often are mapped to a spatial domain.

Time and Processes as PATHS: The conceptualisation of time has been investigated by Boroditsky [2000]. Following suit, this section looks at how members of the PATH-following image schema family are widely used as conceptual metaphors for time. Several examples are considered and the role of PATH-following image schemas for the conceptualisation of processes is discussed.

One popular way to conceptualise time is as MOVEMENT_ALONG_-

[1] Charles Forceville. Theories of conceptual metaphor, blending, and other cognitivist perspectives on comics. In Niel Cohn, editor, *The Visual Narrative Reader*. Bloomsbury, London, 2016

[2] Marco Schorlemmer, Alan Smaill, Kai-Uwe Kühnberger, Oliver Kutz, Simon Colton, Emilios Cambouropoulos, and Alison Pease. COINVENT: Towards a Computational Concept Invention Theory. In *Proceedings of the 5th International Conference on Computational Creativity*, Ljubljana, Slovenia, June 10–13 2014

[3] Oliver Kutz, John A. Bateman, Fabian Neuhaus, Till Mossakowski, and Mehul Bhatt. E pluribus unum: Formalisation, Use-Cases, and Computational Support for Conceptual Blending. In Tarek R. Besold, Marco Schorlemmer, and Alan Smaill, editors, *Computational Creativity Research: Towards Creative Machines*, Thinking Machines. Atlantis/Springer, 2014a

[4] Gilles Fauconnier and Mark Turner. *The Way We Think: Conceptual Blending and the Mind's Hidden Complexities*. Basic Books, 2003

[5] Mark Turner. The Way We Imagine. In Ilona Roth, editor, *Imaginative Minds - Proceedings of the British Academy*, pages 213–236. OUP, Oxford, 2007

[6] George Lakoff and Raphael Núñez. *Where Mathematics Comes From: How the Embodied Mind Brings Mathematics into Being*. Basic Books, New York, 2000

Path. Often, time is conceptualised as having a beginning, a Start_-Path; 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 the Apocalypse.

Other religious traditions embrace the notion of a 'Wheel of Time', that is, time as a cyclic repetition of different aeons. The underlying image schema involves a Cycle and as wheels are associated with physical movement, it can be extended to Movement_In_Loops. The same image schema is used in the conceptualisation of time within calendars: the seasons are a continuous cycle where any winter is followed by a new spring. Similarly, the hours of the day are represented on analogue clocks as 12 marks on a cycle, and the passing of time is visualised as Movement_In_Loops of the handles of the clock.

The conceptualisation of time, in itself, is an interesting example of the usage of image schemas. However, the real significance is that these image schemas can be seen as providing the conceptual skeletal structure for the understanding of processes. Imagine a desire to understand a complex process, for instance, the demographic development of a country, the acceleration of a falling object, or the economic situation of a country. In these situations, humans often use two-dimensional coordinate systems where the vertical axis represents the property in question (e.g. population, speed, GDP, respectively) and the horizontal axis represents time, to transfer the information. These coordinate systems are so useful and so widely applicable because humans can conceptualise arbitrary processes as Movement_Along_Path, where the paths represent some important dimension or aspect of the process.

Path *similes:* In Chapter 3, the Path-following family was introduced and for each family member, linguistic examples were offered. In this section, this linguistic manifestation is used to motivate how this image-schematic skeleton can be used in analogical information transfer through Path similes.

If a target domain *X* from the first column and a source domain *Y* from the second column in Table 6.1 are picked randomly, the resulting simile *X is like Y* will make sense. Of course, depending on the choice of *X* and *Y*, the simile may be more or less intuitive and interesting. Note that the target domains have little or nothing in common. Thus, at least at first glance, one would not expect that one can compare them meaningfully to one and the same source domain.

The similes work because all of the concepts in the second column involve physical Movement_Along_Path, which have some per-

Target Domain	Source Domain
Watching the football game	the swinging of a pendulum
Their marriage	a marathon
The story	escaping a maze
This piece of music	a sailboat during a hurricane
Bob's career	a roller coaster ride
Her thoughts	a Prussian military parade
Democracy in Italy	stroll in the park

Table 6.1: PATH similes: <target> is like <source>.

tinent characteristics. These characteristics may concern the shape of the path itself. For instance, the path of a roller coaster involves many ups and downs and tight curves, the path out of a maze involves many turns, the path of a pendulum is regular and between two points. Or the characteristics can concern the way the movement is performed. For instance, the movement of a sailboat during a storm is erratic and involuntary, a stroll in the park is done leisurely. Or the characteristics can concern the effects the movement may have. For instance, running a marathon is exhausting, a Prussian military parade may be perceived as threatening. In each of the similes, some of the pertinent characteristics of the MOVEMENT_ALONG_PATH in the source domain, are used to describe the process in the target domain. For example, in the simile 'Bob's career is like a Prussian military parade' the career is conceptualised as movement along a 'time path', with career-related events like promotions as sites, or locations, on the path, and transfer characteristics from the movement of a Prussian military parade on this path. Thus, one way to read the simile is that Bob moves through the stages of his career in an exceptionally predictable fashion. The example illustrates how the similes work: first, the process is conceptualised in the target domain as MOVEMENT_ALONG_PATH, where the events of the process are ordered by time, and then some pertinent characteristic(s) of the MOVEMENT_ALONG_PATH of the source domain to the target domain is transferred following the rules of conceptual metaphors. This pattern is not just applicable to the concepts in Table 6.1. As was discussed above, any process can be conceptualised as MOVEMENT_-ALONG_PATH, thus, any process could be added as target domain in Table 6.1. Further, any concept that involves interesting physical movement along some path could be added as source domain. Hence, the use of the image schema MOVEMENT_ALONG_PATH enables the mechanical generation of similes for processes.

CONTAINMENT *similes:* To demonstrate that this phenomenon is not exclusive to PATH image schemas, consider the concepts 'Spaceship', North Korea', 'Spacetime', 'Marriage' and 'Bank account'. While all these concepts differ significantly, they can all be argued to be construed as various kinds of containers. For physical containers such as spaceships, which may contain passengers and cargo, the CONTAINMENT schema is without a doubt. Likewise, geopolitical entities like North Korea instantiate the CONTAINMENT schema, as well since countries and spatial regions in general, have a two-dimensional boundary that people may either be inside or outside of. For more complex concepts such as 'Spacetime', it is conceived as a container as not only space is a container, but time as as well. Despite being a great simplifications of the laws involved within the Theory of Relativity [7], it does not prevent science fiction writers to construe spacetime as a container for planets, stars and other things. For example, in many fictive stories, it is possible to leave and return to the universe (e.g. by visiting a 'parallel universe'). While the first three examples are physical entities, 'Marriage' is an abstract and social entity. Thus, in the literal physical sense marriage cannot be a container. Nevertheless, humans use vocabulary that is associated with containers to describe marriage. In the conceptual space, one can 'enter' and 'leave' a marriage, marriages can be both 'open' and 'closed' which adds specifications to the IN and OUT movements, and people may find happiness 'in' their marriage. Similarly, a 'bank account' may *contain* funds, and if it is 'empty' it is possible to add additional funds 'into' the account in order to later take them 'out' again. This shows that while bank accounts and marriages are conceptually very different entities, it is still possible to say that the CONTAINMENT schema is essential for these concepts.

Similarly, as with the PATH similes above, the CONTAINMENT schema can also be used in similes. The first column (target domain) of Table 6.2 contains the mentioned concepts. The second column (source domain) contains various examples of concrete and physical containers that highlight some possible features of containers: a container may leak, be hard to get out of or have a flexible boundary. Randomly choosing an element from the first column and combining it with a random element in the second column with the structure *X is like a Y*, generates similes. For example, 'The universe is like a treasure chest', 'Their marriage is like a prison', 'My bank account is like a leaky pot'. Note that all of the resulting similes are cognitively meaningful. Some of them will intuitively have more appeal than others, which may only be meaningful within a particular context. For example, 'This spaceship is like a bottomless pit' may sound odd in isolation, but in the context of 'I have already 20.000 containers in storage, and there is still empty cargo space' the simile works.

The fact that Table 6.2 can be used to randomly produce similes is linguistically interesting because the target concepts vary signifi-

[7] Robert DiSalle. Space and time: Inertial frames. In Edward N. Zalta, editor, *The Stanford Encyclopedia of Philosophy*. Metaphysics Research Lab, Stanford University, winter 2016 edition, 2016

Target Domain	Source Domain
This spaceship	leaky pot
North Korea	prison
The universe	treasure chest
Their marriage	bottomless pit
My bank account	balloon

Table 6.2: CONTAINMENT similes: <target> is like a <source>.

cantly. The concepts 'spaceship', 'marriage' and 'North Korea' seem to have nothing in common. Therefore, the fact that they can all be compared meaningfully to the same concepts requires an explanation. Just like with the PATH similes, one answer is found if the notion is accepted that all concepts in the first column share the same underlying image schema, in this case CONTAINMENT. For this reason, they can be blended with the container concepts from the second column. Each simile projects some feature of CONTAINMENT in the source domain via analogical transfer onto the container aspect of the target domain. Thus, Table 6.2 provides evidence that image schemas can help us to identify or construe shared structures between concepts. This follows the invariance principle which argues that for conceptual metaphors to be possible, the same conceptual skeleton is needed.

The shared structure of concepts can be utilised in conceptual blending. For example, it is possible to conceptually blend the concepts 'universe' and 'balloon' into a 'balloon-universe', here with the interpretation that the universe is continuously expanding and eventually will burst. Blending 'spaceship' with 'prison' could lead to various interesting concepts, for instance, a spaceship that is used as a prison.

It is also possible to attempt to blend two different concepts from the first column from Table 6.2. However, since these concepts contain more prominent aspects than CONTAINMENT, these blends may not involve the CONTAINMENT as shared structure. For example, in a blend of 'Spaceship' and 'North Korea' probably other aspects of the concept of North Korea would be more dominant such as that a 'North Korean Spaceship' may be, trivially, a spaceship built in North Korea. Only by providing some additional context one can prime the CONTAINMENT aspect of North Korea into the desired format.

Another example is the blend between 'marriage' and 'bank account' which may yield a concept such as a 'marriage account'. This new concept could be used in sentences like the following: 'Marcus and Susie have just spent a long and happy holiday together, this was a big 'investment' into their marriage account, it is now full of love' or 'Jim needs to watch the way he treats Jill, their marriage account is draining quickly and is nearly empty. She is probably going to leave him'. In this blend, the 'marriage account' is a container which contains positive feelings between the spouses rather than money. The blend inherits the domain from 'marriage', with the major difference that the spouses themselves are no longer inside the container. Some main contributions of 'bank account' to the blend are the ability to 'invest' and 'check the balance' of the content in the 'marriage account'.

In Chapter 5 it was discussed how concepts and events are conceptualised in terms of image schema combinations. One important thing to acknowledge is that the combination is not a fixed variable, but rather how something is conceptualised depends greatly on the context. For example, surgeons may conceptualise people as containers of organs, blood, and various other anatomical entities, but in most contexts, humans are not conceptualised in this way. By choosing the appropriate context, an image schema may be pushed from the background into the conceptual forefront. In most contexts, a 'mother' is not conceptualised as a kind of container. However, in selected contexts, it is possible to generate similes for 'mother' reusing the source domains from Table 6.2, such as in 'The mother is pregnant with twins, she looks like a balloon' or 'The mother is like a prison for the unborn child'.

These examples show how the PATH family and the CONTAINMENT image schema are part of analogical reasoning in their role in similes. In the next section, some formal approaches to analogy and conceptual blending will be introduced before sketching a few examples of how image schemas can be integrated into conceptual blending.

6.2 *Analogy Engines and Computational Conceptual Blending*

One computational analogy framework is the Structure Mapping Theory and the associated implementation that can perform analogical transfer, the Structure Mapping Engine (SME) [8]. By trying to find common relationships in the analogy's source and target domain, the system performs generalisations to identify the involved structures. Similarly, the analogy engine Heuristic Driven Theory Projection (HDPT) computes a 'least general generalisation' of two input spaces through anti-unification[9] [10]. Both of these systems rely on a purely syntactic approach without any considerations to the involved information in the domains, thus often performing poorly by making inappropriate and incorrect inferences.

Also for computational concept invention image schemas could play an important role [11]. Conceptual blending, a cognitive framework for concept invention, builds on the idea that creative gener-

[8] Dedre Gentner. Structure mapping: A theoretical framework for analogy. *Cognitive Science*, 7(2):155–170, 1983

[9] In computer science anti-unification is a process in which two symbolic expressions are searched for a common generalization.

[10] Martin Schmidt, Ulf Krumnack, Helmar Gust, and Kai-Uwe Kühnberger. Heuristic-Driven Theory Projection: An Overview. In H. Prade and G. Richard, editors, *Computational Approaches to Analogical Reasoning: Current Trends*, volume 548 of *Computational Intelligence*, pages 163–194. Springer, 2014a

[11] Roberto Confalonieri, Enric Plaza, and Marco Schorlemmer. A process model for concept invention. In *Proceedings of the 7th International Conference on Computational Creativity (ICCC)*, 2016

ation comes from the blending of already known information and takes generalisations such as image schemas into account [12]. When building novel concepts through combination, there are several aspects that need to be taken into account to make sure that the resulting concept is consistent. Confalonieri et al. [2016] propose a formal model for blending image schemas with the objective of concept invention. Their computational model captures the process by using logical operators such as anti-unification and a knowledge representation language called *feature terms*.

6.2.1 *The Major Problem with Computational Conceptual Blending*

One problem for computational conceptual blending, and related work such as analogy engines (e.g. Structure Mapping Engine (SME) [13,14] and Heuristic-Driven Theory Projection (HDPT) [15]) is the generation of a 'sensible' blend. In Chapter 1, this was discussed in relation to the example with the gryphon where less successful blends of a lion and an eagle, would be equally possible. In a completely automatized system, there is currently no simple way to distinguish the blends that a human would consider meaningful from those that lack cognitive value in the context of the input spaces. This problem grows exponentially in relation to the size of the input spaces. The larger the input spaces, the more combinations can be generated resulting in a multitude of possible blends, most of which will make little sense if evaluated by humans. In real life scenarios, the amount of information in the input spaces can be vast, complicating the process for successful concept invention tremendously when looked at as a formal, combinatorial problem.

A proposal to explain the ease with which humans perform blending is given via the ideas of *packing and unpacking*, as well as *compression and expanding* of conceptual spaces, as outlined by Turner [2014]. These terms aim to capture how we mentally carry around ideas as compressed 'idea packages' that we can 'unpack' and utilise in different contexts on the fly. These packages are designed to be hooked into our surroundings to be used appropriately there. The process of packing and unpacking ideas is important for the contextualised usage of conceptual blends in various situations. Generally, the idea of *Optimality Principles* in blending theory is meant to account for an evaluation of the quality and appropriateness of the resulting blends [16].

However, there is currently no general formal proposal how such optimality principles could be implemented computationally, apart from some work on turning such principles into metrics for rather lightweight formal languages [17].

[12] Gilles Fauconnier and Mark Turner. Conceptual integration networks. *Cognitive Science*, 22(2):133—187, 1998

[13] Dedre Gentner. Structure mapping: A theoretical framework for analogy. *Cognitive Science*, 7(2):155–170, 1983

[14] Kenneth D. Forbus, Brian Falkenhainer, and Dedre Gentner. The structure-mapping engine. *Artificial Intelligence*, 41:1–63, 1989

[15] Martin Schmidt, Ulf Krumnack, Helmar Gust, and Kai-Uwe Kühnberger. Heuristic-Driven Theory Projection: An Overview. In H. Prade and G. Richard, editors, *Computational Approaches to Analogical Reasoning: Current Trends*, volume 548 of *Computational Intelligence*, pages 163–194. Springer, 2014a

[16] Gilles Fauconnier and Mark Turner. *The Way We Think: Conceptual Blending and the Mind's Hidden Complexities*. Basic Books, 2003

[17] Francisco C. Pereira and Amilcar Cardoso. Optimality Principles for Conceptual Blending: A First Computational Approach. *AISB Journal*, 1(4), 2003; and Joseph Goguen and D Fox Harrell. Style as a choice of blending principles. *Style and Meaning in Language, Art Music and Design*, pages 49–56, 2004

The problem is not just one of applying enough forward constraints and optimality principles. In the CRIME-model found in [Veale et al., 2013], this problem is approached by constraining the search. The authors argue that blending must be considered in a task-specific context, simultaneously working forward from the input spaces and backward from the desired elements of the blended space.

6.2.2 *Formalisation of Conceptual Blending*

The approach to formalising conceptual blending is based on Goguen's [1999] work on *Algebraic Semiotics* in which certain structural aspects of semiotic systems are logically formalised in terms of algebraic theories, sign systems, and their mappings. In [Goguen and Harrell, 2010] algebraic semiotics has been applied to user interface design and conceptual blending. Algebraic semiotics does not claim to provide a comprehensive formal theory of blending. Indeed, Goguen and Harrell admit that many aspects of blending, in particular concerning the meaning of the involved notions, as well as the optimality principles for blending, cannot be captured formally. However, the structural aspects *can* be formalised and provide insights into the space of possible blends. The formalisation of these blends can be formulated using languages from the area of algebraic specification, for instance OBJ3 [18].

Hois et al. [2010] and Kutz et al. [2012, 2014b] present an approach to computational conceptual blending, based on the tradition of Goguen's proposal (see Figure 6.1). In this approach, the input spaces were suggested to be represented as ontologies, for example, in the Web Ontology Language (OWL) [19]. Here also the structure that is shared across the input spaces, namely the generic space, is also represented as an ontology, which is linked by mappings to the input spaces. As proposed by Goguen, the blending process is modelled by a colimit computation, a construction that abstracts the operation of disjoint union modulo the identification of certain parts specified by the base and the interpretations, as discussed in detail by Goguen [2003] and Kutz et al. [2012].

Regarding blending diagrams as displayed in Figure 6.1, notice the following discrepancy in terminology and in the way the basic blending process is visualised. In the cognitive science literature, following Fauconnier and Turner [1998], conceptual blending is visualised as shown in Figure 1.6, with a *generic space* at the top identifying commonalities. In the technically oriented literature following Goguen and Harrell [2010], the formalisation of this process is represented as a diagram as shown in Figure 6.1 with the generic space, or base ontology, at the bottom. This kind of diagram is, on the one hand, an

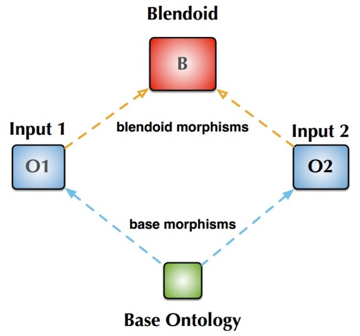


Figure 6.1: The blending process using ontologies as input spaces and as the generic space, here referred to as base ontology.

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[18] Joseph Goguen and Grant Malcolm. *Algebraic Semantics of Imperative Programs.* MIT Press, 1996

[19] 'OWL' refers to OWL 2 DL, see `http://www.w3.org/TR/owl2-overview/`

upside-down version of the first illustration, following a tradition in mathematical diagrams where simpler concepts are often placed at the bottom. On the other hand, it replaces the term 'generic space' with 'base space', partly because of a clash with mathematical terminology. The formalisation of blending presented makes no technical difference between 'generic space' and 'base space' and treat them as synonymous.

The inputs for a blending process, namely, input concepts, generic space and mappings, can be formally specified in networks, sort of *blending diagrams*, in the Distributed Ontology, Model, and Specification Language (DOL).

6.2.3 *Identifying the Structure in the Base Space*

As illustrated with the examples of similes in Section 6.1.2, a critical step in the blending process is the identification of the common structure of the generic space and its mapping to the input spaces. The structural similarity between conceptual blending and analogical thinking suggests to investigate and apply approaches to analogical reasoning as tools for computational conceptual blending.

One way to determine what is common to the input spaces is by means of looking at the cross-space mapping between them. Hence, structural mapping techniques that identify isomorphic substructures of the inputs might be useful to create an abstraction of this substructure. Here, cross-space mappings are established by means of the HDTP algorithm [20], which computes a restricted higher-order anti-unification of two input spaces represented as first-order logical theories. This anti-unification then serves as a generic space for the blend of the original first-order theories. The algorithm is built on the Structure Mapping Theory [21] which argues that analogical reasoning is characterised by the relationships between objects in the different domain rather than their attributes. HDTP computes a 'least general generalisation' B of two input spaces I_1 and I_2. This is done by anti-unification to find common structure in both input spaces I_1 and I_2. HDTP's algorithm for anti-unification is, analogously to unification, a purely syntactical approach that is based on finding matching substitutions. Another method for finding generalisations is presented in the *Analogical Thesaurus* which uses *WordNet*[22] to identify common categories for the source and target spaces [23].

While these are interesting approaches, they have a major disadvantage. Typically, for any two input spaces there exists a large number of potential generalisations. Thus, the search space for potential base spaces and potential conceptual blends is vast. HDTP implements heuristics to identify interesting anti-unifiers. In other

[20] Martin Schmidt, Ulf Krumnack, Helmar Gust, and Kai-Uwe Kühnberger. Heuristic-Driven Theory Projection: An Overview. In H. Prade and G. Richard, editors, *Computational Approaches to Analogical Reasoning: Current Trends*, volume 548 of *Computational Intelligence*. Springer, 2014b

[21] Dedre Gentner. Structure mapping: A theoretical framework for analogy. *Cognitive Science*, 7(2):155–170, 1983

[22] "WordNet© is a large lexical database of English. Nouns, verbs, adjectives and adverbs are grouped into sets of cognitive synonyms (synsets), each expressing a distinct concept. Synsets are interlinked by means of conceptual-semantic and lexical relations." See `https://wordnet.princeton.edu` for more information.

[23] Tony Veale. The analogical thesaurus. In J. Riedl and R. Hill, editors, *Proceedings of the 15th Innovative Applications of Artificial Intelligence Conference*, pages 137–142. AAAI Press, 2003

words, it prefers anti-unifiers yielding rich theories over anti-unifiers yielding weak theories. However, since anti-unification is a purely syntactical approach, there is no way to distinguish cognitively relevant from irrelevant information. As a result, an increase in the size of the two input ontologies leads to an explosion of possibilities for anti-unifications, which is the major problem for computational conceptual blending.

6.3 *Image Schemas in Conceptual Blending*

Instead of relying on a purely syntactical approach to blending, the semantic content found in image schemas can be employed to help guide the blending process. The basic idea here is that in order to identify common structure sufficient for defining a useful generic space for two, or more, given input spaces, it is possible to search for shared image-schematic information rather than arbitrary structure. Given the powerful role that image schemas generally seem to play in human conceptual (pre-linguistic) development, the working hypothesis is that the semantic content and cognitive relevance given by identifying shared image schemas will provide valuable information for constructing and selecting the more substantial or interesting possible blends.

Two methods will be discussed in which image schemas can improve the computational blending process. Image schemas can provide heuristics for, first, detecting conceptually valuable information from each input space and, second, for identifying suitable base spaces. In the upcoming sections, these methods will be discussed in more detail. In addition, the structuring of image schemas into family hierarchies presented in Chapter 3 will be demonstrated to be a valuable asset in these processes. To provide support for the usefulness of these methods, a series of examples will be presented.

6.3.1 *Method One: Image Schema Prioritisation*

The first method is rather straightforward. The presumption that image schemas are conceptual building blocks pushes the hypothesis that they are valuable pieces of information that surpass the information present in other properties such as visual cues. As argued for in Chapter 2 image schemas are tightly connected to affordances which connects the objects and concepts to the 'uses' they afford, e.g. a cup affords actions involving CONTAINMENT such as 'pouring coffee IN/OUT' or 'containing liquid'. When novel concepts are created through conceptual blending, it is reasonable to assume that these affordances play a central role also in the emerging blend.

The Houseboat Example

The benefit of inheriting image schemas can be demonstrated with the classic blends, the 'Houseboat' and the 'Boathouse'. Both blended concepts are generated from the merge of the conceptual spaces 'house' and 'boat' (see Goguen [1999], Kutz et al. [2014b] for formalisations of the Houseboat example). Taking a closer look at the 'houseboat' example, which consists of a house to live in that also functions as a boat, the idea of giving higher priority to image-schematic content can be illustrated.

One of the most apparent image schemas associated with the input space 'house' is Containment. One lives 'in' houses, houses 'contain' rooms and furniture, it is possible to go 'into', 'out of' and 'through' a house, basically embodying both the static and the dynamic aspects of Containment presented in Section 5.3. While boats also can be containers, and therefore follow the same structure, the most prominent feature of boats is that they can transport people and goods from one point to another along a water-based path, capturing the Source_Path_Goal image schema. Consequently, one of the most cognitively interesting blends that can arise from this merge is the 'houseboat' as it contains both of these essential image schemas (see Figure 6.2 for an illustration).

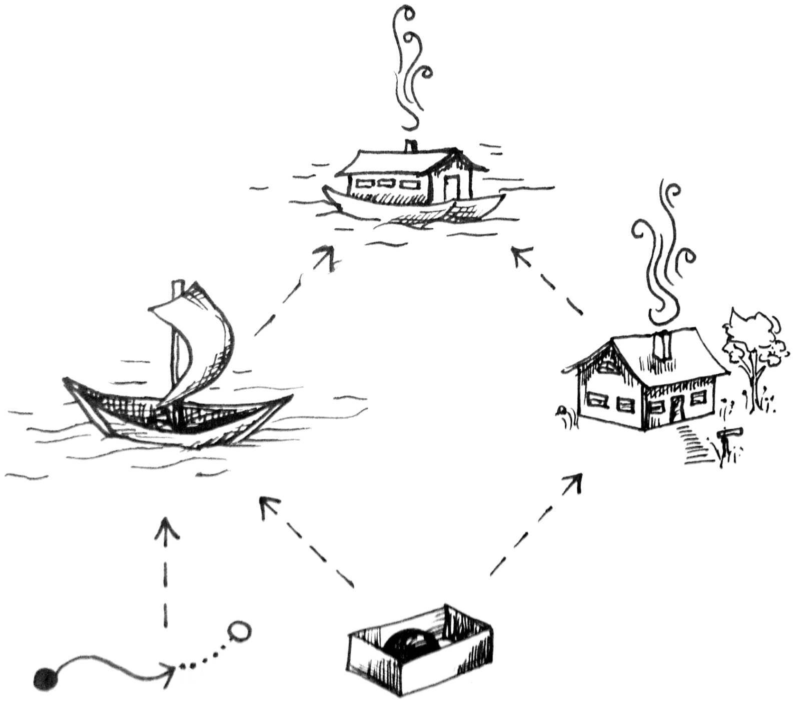

Figure 6.2: The Blending of Houseboat. Here, both input spaces share the Containment schema, but only the input space 'boat' contains the Source_Path_Goal schema. For the blended space 'houseboat' both image schemas are present.

The blend 'boathouse' is another 'sensible' merge that can take place, but it contains a distinct difference. Here the mapping is not between the conceptual spaces houses and boats as a whole, but between particular aspects, or subsets, of the inputs. Instead of making the boat a house and the house a boat, as in 'houseboat', the 'boathouse' remains entirely a house. The information transfer is based on a conceptual mapping between 'people' and 'boats'. This means that the blending process maps 'people *live_in* houses' to 'boats *live_in* boathouses'. As the blend behaves more like a conceptual metaphor in which a CONTAINMENT related affordance from the conceptual space 'house' is mapped directly to the conceptual space 'boat', the SOURCE_PATH_GOAL schema is disregarded as it is not included in the part of the input space that is responsible for the information transfer. This means that for each input space that is blended the present image schemas play a central role in the information transfer. Figure 6.3 shows the blending diagram made by HETS to illustrate the relationships between the input spaces and the blended concepts 'houseboat' and 'boathouse'.

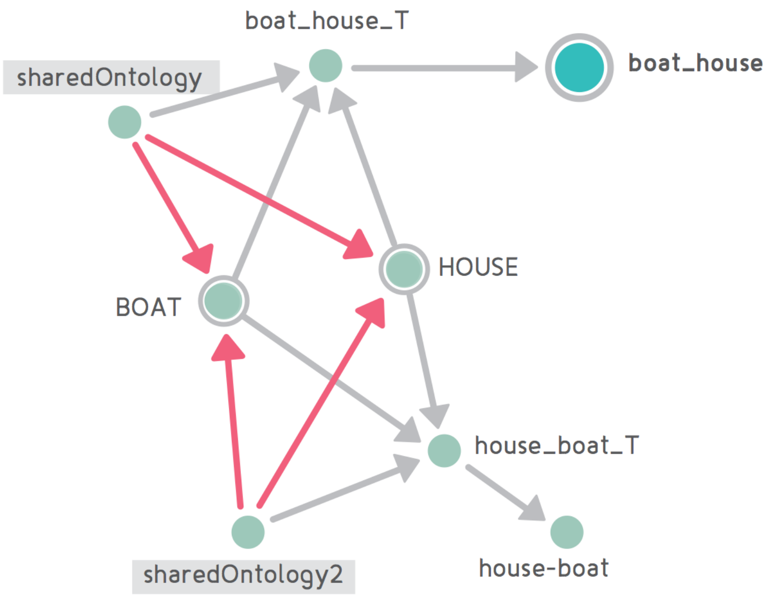

Figure 6.3: The blending diagram of houseboat and boathouse created with HETS on Ontohub.

6.3.2 *Method Two: Image Schemas Projection*

Another way to use image schemas in blending is to identify them as the prime ingredient for the construction of a generic space. When performing the search for common structure in the different input spaces, the search can be guided by mapping (parts of) the content of the input spaces to nodes in a library of formally represented image schemas. As image schemas hold semantic value in the form of spatial relationships, the blends would be based on the same content. In theory, this is similar to classic structure mapping that preserves relationships, but as image schemas model affordances [24] such as 'live_in' (CONTAINMENT) in the example of 'boathouse' in Section 6.3.1, which by definition have higher cognitive value, the blend will inherit such information as well.

The Mothership Example

The mothership example relies on the idea that image schemas can successfully constitute the generic space in the conceptual blending process as both the input concepts 'spaceship' and 'mother' share the CONTAINMENT schema.

In Chapter 5, CONTAINMENT was formally represented using ISL^{FOL}. In this section, the static form of CONTAINMENT will be put to use to describe the search for a generic space, see below.

$$\forall O_1, O_2{:}Object\ (\text{Contained\_Inside}(O_1, O_2) \leftrightarrow PP(O_1, \mathsf{inside}(O_2)))$$

The static representation of CONTAINMENT.

Here containers are defined as objects that have an inside, and for something to be Contained_Inside it, more precisely the space input O_1 occupies, needs to be proper part of that inside.

As previously mentioned, many conceptual spaces contain an information-rich structure. Naturally, no attempt is made to provide a full axiomatisation of the input spaces 'mother' nor 'spaceship', but simply to focus on some salient points for the sake of illustrating the blending process.

In Section 6.1.2, it was argued that 'Mother' realises the CONTAINMENT schema since women can 'contain' unborn children. More specifically, woman have insides and a proper part of that inside is a 'uterine cavity', which, in the case with (biological) mothers, at some point contained some child. For adult children, the pertinent relationship between mother and child is 'parent_of'.

$$\begin{aligned} \forall M{:}Object\ (Mother(M) \rightarrow \\ \exists K{:}Object, \exists U{:}Region\ (Female(M) \wedge Human(K) \wedge \\ Parent\_of(M, K) \wedge \mathsf{cavity\_of}(U, M) \wedge \text{Contained\_Inside}(U, M))) \end{aligned}$$

Mothers, M, are described as females that are parents of humans, K, have a UterineCavity, U, that is Contained_Inside the Mother.

As Spaceships are a subcategory of vehicles, these need to be defined first. Vehicles are defined as objects with an inside, basically

[24] Werner Kuhn. An Image-Schematic Account of Spatial Categories. In Stephan Winter, Matt Duckham, Lars Kulik, and Ben Kuipers, editors, *Spatial Information Theory*, volume 4736 of *Lecture Notes in Computer Science*, pages 152–168. Springer, 2007

defining them as containers, as well as given the Source_Path_Goal image schema. While vehicles may be at rest, the Source_Path_Goal schema requires a path for 'potential' movement. From this, is it possible to define spaceships, which are described as vehicles Contained_Inside space, rather than on Earth, and that may have CargoSpace as a cavity_of that is a proper part of the inside of the vehicle.

$$\begin{aligned} &\forall V{:}Object\ \big(Vehicle(V) \rightarrow \\ \forall O{:}Object(has_sourcepathgoal(O) \leftrightarrow \exists P{:}&Path(sourcepathgoal(O,p))) \\ &\exists I{:}Region\ (has\_\textsc{Source\_Path\_Goal}(V)\wedge \\ &\text{Contained\_Inside}(I,V))\big) \end{aligned}$$

Vehicles, V, are described as objects that have the image schema Source_Path_Goal, and have an inside, I.

$$\begin{aligned} &\forall S{:}Object\ (SpaceShip(S) \rightarrow \\ \exists C, Space{:}Region\ (&Vehicle(S) \wedge \text{Contained\_Inside}(S, Space) \wedge \\ CargoSpace(C)\ \wedge\ &\mathsf{cavity\_of}(C,S)\ \wedge \text{Contained\_Inside}(C,S))) \end{aligned}$$

Spaceships, S, are described as vehicles, and thus inherit the image schema Source_Path_Goal, they are Contained_Inside in Space rather than on Earth and have a CargoSpace, C, that is Contained_Inside the Spaceship.

During the blending into 'mothership', the Containment structure of both input spaces is preserved, see below. The uterine cavity and the cargo space are both mapped to the docking space. The 'mothership' inherits some features from both input spaces, while others are dropped. Obviously, a mothership is a space travelling vessel. But like a mother, it is a 'parent' to some smaller entities of the same type. These smaller vessels can be contained within the mothership, they may leave its hull (a process analogous to a birth) and are supported and under the authority of the larger vessel.

$$\begin{aligned} &\forall MS{:}Object(MotherShip(MS) \rightarrow \\ &\exists S{:}Object, \exists D, Space{:}Region\ (Vehicle(MS)\ \wedge \\ \text{Contained\_Inside}(D, MS)\ \wedge DockingPlace(D)\ \wedge &\mathsf{cavity\_of}(D, MS)\ \wedge \\ &\text{Contained\_Inside}(MS, Space)\ \wedge \\ &Parent\_of(MS,S) \wedge SpaceShip(S))) \end{aligned}$$

MotherShips, MS, are described as the union of SpaceShips, S, and Mothers. In this example, in addition to Containment, both the image schema Source_Path_Goal from the SpaceShip input, as well as the Parent_of relationship from the Mother input is inherited into the blend.

To summarise, in this example the input spaces of 'mother' and 'spaceship' are blended. Instead of trying to utilise a syntactic approach like anti-unification to search for a base space, it is recognised that both input spaces have cavities and, thus, are containers. Using the base space Containment in the blending process yields a blended concept of 'mothership' (see Figure 6.4). Here, the precise mappings from the base space axiomatisation of Containment to

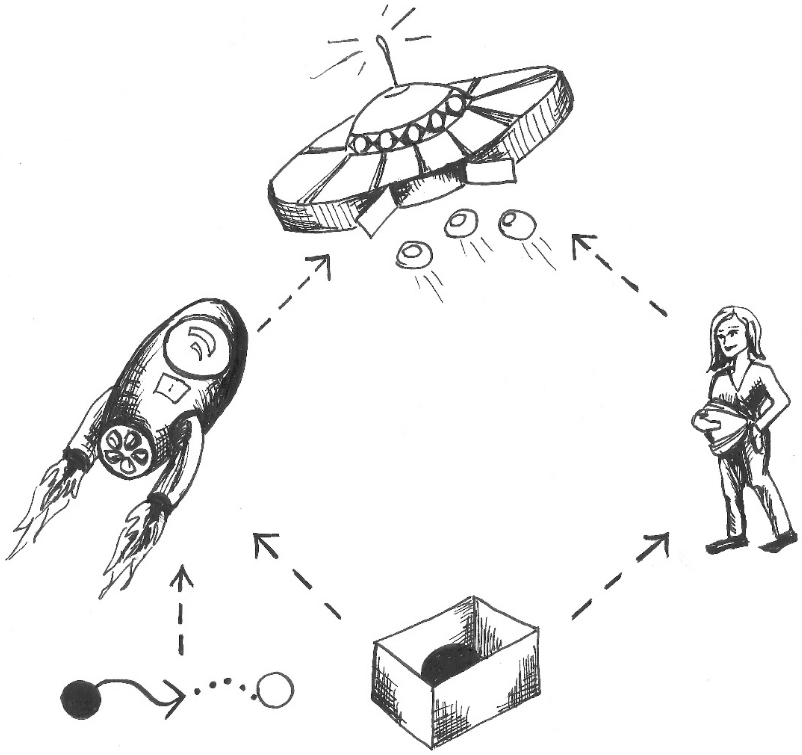

Figure 6.4: In the blending of mothership the blend inherits properties and characteristics from each input space. As both input spaces have the CONTAINMENT schema, this is automatically inherited. Additionally, the SOURCE_PATH_GOAL image schema found in the spaceship is also given priority in the blending process.

the two input spaces regulate the various properties of the blended concept. Note also that the principle of image schema prioritisation can also be applied for cases when an image schemas is only present in one of the input spaces. For instance, one can argue that mothers also have the Source_Path_Goal schema, as they have the capacity for Self_Movement, a high-level image schema capturing not only Source_Path_Goal but also agency. In the next section, a method will be discussed to use the image schema family structure presented in Chapter 3, as a tool to identify members of the same family in several input spaces.

Blending with the Family Hierarchy

Chapter 3 presents in detail the idea that image schemas should be formally approached as interconnected families of theories, that are partially ordered by generality. This section demonstrates the formal benefits of using a family structure to represent image schemas and how this also has benefits when performing computational conceptual blending.

Figures 6.5 and 6.6 show two basic ways of using image schemas within the conceptual blending workflow. In both cases, the image-schematic content takes priority over other information the input concepts might contain. In Figure 6.5, following the core model of blending described in Section 1.6, the different spatial structures are first identified within the same image schema family in the input concepts. They are then generalised to the most specific, common version within the image schema family to identify a generic space, using the pre-determined graph of image schemas (i.e. one can search for the least upper bound in the family hierarchy is computed).

The second case, Figure 6.6, illustrates the situation to first specialise or complete the (description of the) image schemas found in the input concepts, before performing a generalisation step and to identify the generic space. This means moving down in the graph of the image schema family and choosing a more specified member. Of course, also a mix of these two basic approaches is reasonable, in other words, where one input's image schema is specialised within a family whilst the other is generalised in order to identify a generic space based on image-schematic content.

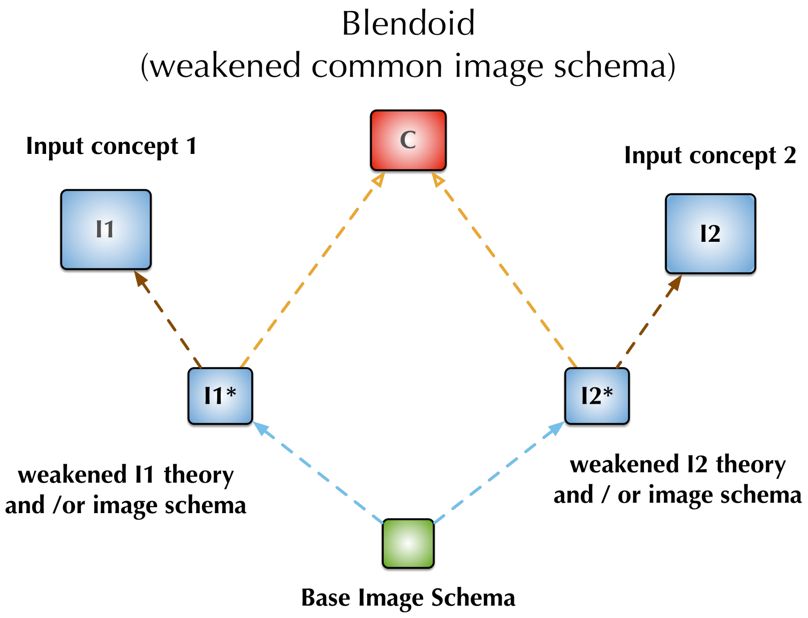

Figure 6.5: Blending using common image schemas through theory weakening.

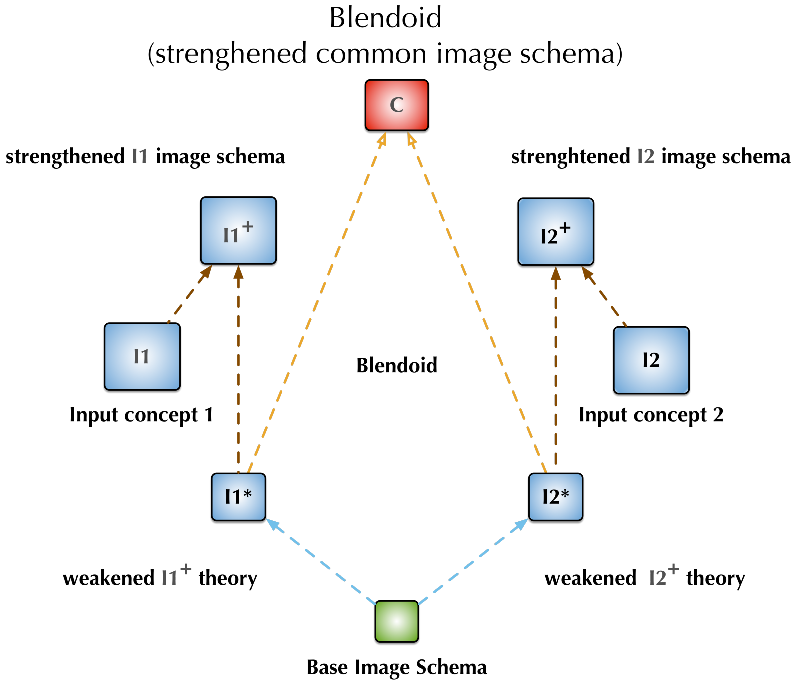

Figure 6.6: Blending using common image schemas through theory strengthening.

6.4 *Complicated Problems: Recognising and Generalising Image Schemas*

To implement computationally the idea of using image schemas as generic spaces, two independent algorithmic problems have to be solved. Namely, 1. the *Recognition Problem*: to identify an image-schematic theory within an input theory, and 2. the *Generalisation Problem*: to find the most specific image schema common to both inputs.

To address the recognition problem, suppose a theory graph $\mathfrak{F}$ encoding an image schema family is fixed. For simplicity, it is assumed that elements of $\mathfrak{F}$ will be logical theories in a fixed formal logic, say ISL^{FOL} with first-order logic elements[25]. Given an input theory I_1 and $\mathfrak{F}$, solving the recognition problem means finding a member $f \in \mathfrak{F}$ that can be *interpreted* in I_1, that is, such that a renaming σ of the symbols in f (called a signature morphism) is found and such that $I_1 \models \sigma(f)$ (also written $I_1 \models_\sigma f$).[26] Note that this is a more general statement than claiming the inclusion of the axioms of f (modulo renaming) in I_1 (the trivial inclusion interpretation) since establishing the entailment of the sentences in $\sigma(f)$ from I_1 might in fact be non-trivial, and the axioms needed for this quite different from the ones in f.

Computational support for automatic theory-interpretation search in first-order logic is investigated in [Normann, 2008], and a prototypical system was developed and tested as an add-on to the Heterogeneous Tool Set (HETS) [27]. Experiments carried out in [Normann and Kutz, 2009, Kutz and Normann, 2009] showed that this works particularly well with more complex axiomatisations in first-order logic, rather than with simple taxonomies expressed in, for instance, OWL . This is because, in the latter case too little syntactic structure is available to control the combinatorial explosion of the search task. From the point of view of interpreting image schemas into non-trivial axiomatised concepts, this can be seen as an encouraging fact, as image schemas are, despite their foundational nature, complex objects to axiomatise. This was the main reason for the content in Chapter 4 which introduces ISL^{FOL}.

Once the recognition problem has been solved in principle, the given theory graph structure of the image schema family $\mathfrak{F}$ provides a simple handle on the generalisation problem. Namely, given two input spaces I_1, I_2, and two image schemas f_1, f_2 from the same family $\mathfrak{F}$ (say, 'CONTAINMENT') such that $I_1 \models_{\sigma_1} f_1$ and $I_2 \models_{\sigma_2} f_2$, compute the most specific generalisation $G \in \mathfrak{F}$ of f_1 and f_2, that is their least upper bound in $\mathfrak{F}$. Since the signature of G will be included in both signatures of f_1 and f_2, one obtains that $I_1 \models_{\sigma_1} G$

[25] Note that none of the ideas presented here depend on a particular, fixed logic. Indeed, heterogeneous logical specification is central to formal blending approaches, see Kutz et al. [2014a].

[26] In more detail: a theory interpretation σ is a signature morphism renaming the symbols of the image schema theory f and induces a corresponding sentence translation map, also written σ, such that the translated sentences of f, written $\sigma(f)$, are logically entailed by I_1.

[27] Till Mossakowski, Christian Maeder, and Klaus Lüttich. The Heterogeneous Tool Set. In Orna Grumberg and Michael Huth, editors, *TACAS 2007*, volume 4424 of *Lecture Notes in Computer Science*, pages 519–522. Springer, 2007

and $I_2 \models_{\sigma_2} G$. $G \in \mathfrak{F}$ is, therefore, an image schema common to both input spaces and can be used as generic space.

In order to implement this idea, a sufficiently comprehensive library of formalised image schemas like those presented in Chapter 3, 4 and 5, needs to be made available for access by a blending engine. For now, this endevour is left for future work (see the Conclusion and Future Work).

6.5 *Examples: Blending with Image Schema Families*

Example One: The Spacestation

Imagine the blended concept that can arise when the previously blended 'mothership' is yet again blended, this time with a 'moon'. Disregarding astronomical definitions, let us allow a moon to be constrained to be defined as a celestial body that is part of some solar system, consists of stone, and orbits around a planet (see below). Of course, many people would associate additional information with the concept 'moon', but even with these limited aspects, there are already enough different possibilities on how these two concepts can be blended. For instance, a structure mapping approach would likely first try to identify the parthood relationship between the docking station and the mothership on one hand with the parthood relationship between the moon and the solar system. This may lead to the concept of a Moon/DockingPlace that is part of a SolarSystem/-MotherShip. While this is not incorrect, it does not provide for a particularly useful concept.

$$\begin{aligned}\forall Mo{:}Object,\ \big(Moon(Mo) \rightarrow\\ \exists P, Stone{:}Object, \exists So{:}Region\ (Consists\_of(Mo, Stone) \wedge\\ has\_shape(Mo, Spherical)\ \wedge\ CelestialBody(Mo)\ \wedge\\ CelestialBody(P)\ \wedge\ \textsc{Revolve\_Around}(Mo, P)\\ \wedge SolarSystem(So)\ \wedge \text{Contained\_Inside}(Mo, So)\ \wedge\\ \text{Contained\_Inside}(P, So))\big)\end{aligned}$$

Moons, *Mo*, are defined as CelestialBodies that have the image schema REVOLVE_AROUND by circling a Planet, *P*. Both planets and moons are Contained_Inside in a SolarSystem, *So*.

In contrast, if one utilises shared image schemas as heuristics for conceptual blending, it is quite natural to look at a different place for blending opportunities. As a mothership is a kind of vehicle, it has the capability to move things or people from one place to another along a path (CONTAINMENT and SOURCE_PATH_GOAL). A moon also moves along a path, namely, an orbit around a planet, its focal point, (REVOLVING_MOVEMENT). Both SOURCE_PATH_GOAL and REVOLVING_MOVEMENT are part of the introduced PATH family, therefore, this information can be utilised in the blending process despite them not instantiating the same image-schematic structure.

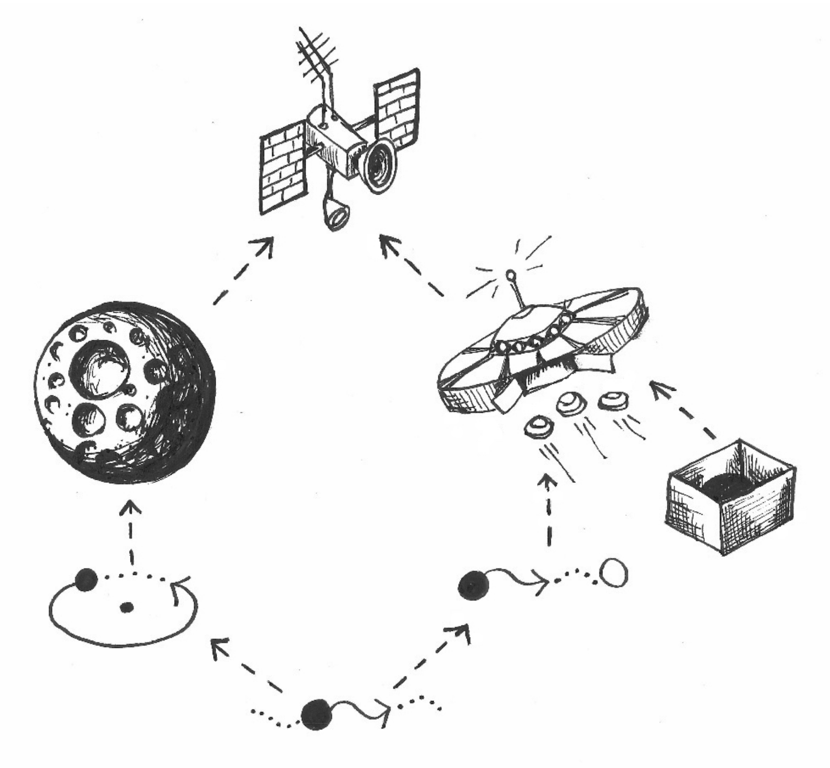

Figure 6.7: In the blending process of spacestation, the blend inherits the Revolve_Around from the input space moon. It is possible to identify the that both input spaces share the Source_Path_Goal movement by backtracking in the Path family. The spacestation, also the Containment schema is inherited from the mothership input space.

As discussed in Chapter 3, image schemas can be enriched by adding additional spatial primitives; the image schemas instantiated by the movement of a vessel and of a moon, respectively, are different (and mutually exclusive) refinements of Movement_Of_Object. For the purpose of blending, the important lesson is that image schemas do not exist in isolation, but they are members of *families of image schemas*. The members of these image schema families are variants of some root conceptualisation (e.g. movement) and can be partially ordered by their strength.

One can utilise this observation as a heuristic for conceptual blending: if two concepts involve two different image schemas, which are within the same image schema family, then a good candidate for the base space for blending both concepts is the *least general* member of the image schema family that generalises the image schemas in the input spaces. In this case, the least general member of the Path family that is common to both input spaces is Movement_Along_Path. This idea is further motivated as the blended concept should probably include only one member of each image schema family. In

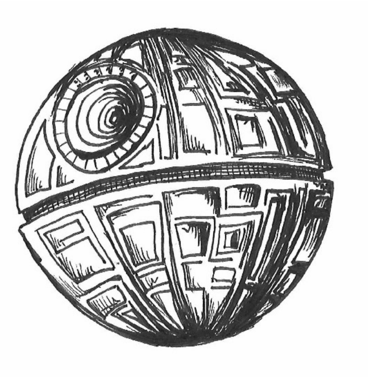

Figure 6.8: An illustration of what a 'moonship' blend could look like.

this example, it is possible to create a new concept that inherits the salient features of the mothership but replaces its ability to travel from one place to another by some orbital movement. The resulting theory describes a 'spacestation', which orbits around a planet (see formalisation below and Figure 6.7). Alternatively, it is possible to think of a moon-like concept that is given the Source_Path_Goal instead of Revolve_Around. One concepts resulting from such a blending outcome, would be a 'meteor' that travels on a path from a point in space into the atmosphere and potentially also the surface of a planet. A more 'creative' concept would be a spacefaring moon. This is a kind of 'moon ship' that while being 'a moon' it has the capability to move from a location of origin along a path to a destination (see Figure 6.8 for an illustrated example).

$$\begin{aligned}\forall Sa{:}Object\ \big(Spacestation(Sa) \rightarrow{}\\ \exists P{:}Object, \exists D, So{:}Region\ (Vehicle(Sa)\ \wedge Planet(P) \wedge{}\\ SolarSystem(So)\ \wedge \textsc{Revolve\_Around}(Sa,P) \wedge{}\\ \mathsf{cavity\_of}(D,Sa)\ \wedge DockingPlace(D)\\ \wedge \text{Contained\_Inside}(D,Sa)\ \wedge\ \text{Contained\_Inside}(Sa,So) \wedge{}\\ \text{Contained\_Inside}(P,So)\big)\end{aligned}$$

Spacestation, *Sa*, are defined as vehicles, thus they have the image schema Source_Path_Goal, additionally this has been strengthened to the image schema Revolve_Around from the input space moon as both circle around a planet, *P*. Both planets and spacestations are Contained_Inside in a SolarSystem, *So*.

$$\begin{aligned}\forall MoS{:}Object\ \big(MoonShip(MoS) \rightarrow{}\\ \exists So{:}Region\ (Vehicle(Mos)\ \wedge\ has\_shape(Mo, Spherical) \wedge{}\\ SolarSystem(So)\ \wedge\ \text{Contained\_Inside}(MoS, So))\big)\end{aligned}$$

Moonships, *MoS*, are defined as Vehicles, thus they have the image schema Source_Path_Goal, from the input space moon they inherit the material *Stone* as well as that they are Contained_Insidea solarsystem, *So*.

Example Two: The Stream of Consciousness vs. the Train of Thought

As outlined in Section 6.1.2, processes can easily be combined with a variety of more specific Path-following schemas. More specifically, this section explores the basic idea how to combine the input space of 'thinking process', which involves only an underspecified kind of 'movement of thoughts', with a second input space that carries a clearly defined Path-following image schema. This leads intuitively to a number of more or less well known conceptual metaphors, including 'train of thought', 'line of reasoning', 'derailment', 'flow of arguments', or 'stream of consciousness', amongst others. Indeed, a central point this section stresses is that these blends work well and appear natural because of the effectiveness of the following heuristics, derived from the formal considerations in Section 6.4:

1. given two input spaces I_1 and I_2, search for the strongest version

G of some image schema that is *common to both*, according to the organisation of a particular image schema family $\mathfrak{F}$;

2. use G as generic space; and

3. use again $\mathfrak{F}$ to identify the stronger version of G, say G', inherent in one of the two inputs, and use the semantic content of G' to steer the overall selection of axioms for the blended concept.

This process will be informally illustrated. Let us briefly consider the concepts of 'stream of consciousness', 'train of thought', and 'line of reasoning'[28].

On a first inspection, the image schema of movement related to 'thinking' might be identified as MOVEMENT_OF_OBJECT, as there is not necessarily a PATH that can be identified. Indeed, in Figure 3.3, MOVEMENT_OF_OBJECT is marked as an 'entry point' to the PATH-following family.

The *stream of consciousness* may be seen as an unguided flow of thoughts, in which topics merge into each other without any defined steps, but rather in a continuous manner. It lacks a clear START_-PATH and has no guided movement towards a particular END_-PATH. It resembles the more basic forms of PATH-following that, according to Mandler and Cánovas [2014], is simply movement in any trajectory.

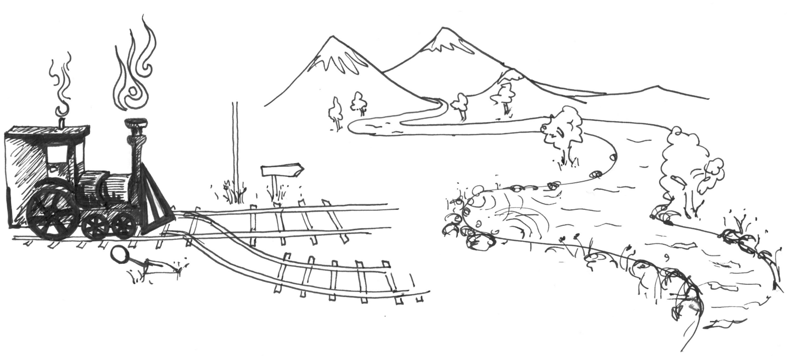

Figure 6.9: The picture aims to visualise a conceptual difference between the idioms train of thought and stream of consciousness.

As any conceptual metaphor, 'train of thought'[29] can be conceptualised in various ways. It differs from a 'stream of consciousness' by having a more clear direction, often with an intended END_PATH. It is possible to say that one 'lost their train of thought', or that 'it was hijacked' or how 'it reversed its course'. The 'train' may be understood as a chain-like spatial object, in which case 'losing the train' decodes to 'disconnecting the chain', or more plainly as a locomotive. In the Pixar film 'Inside Out' (2015), the 'Train of Thought' is

[28] The examples presented here are chosen to illustrate the basic ideas how to employ families of image schemas in blending. It is not intended to capture fully the meaning of these terms as they are used in the psychological or linguistic literature, or indeed the subtle meaning they might carry in natural language.

[29] The expression 'train of thoughts' appears to have been first used by Thomas Hobbes in his book Leviathan (1651): "By 'consequence of thoughts' or 'TRAIN of thoughts' I mean the occurrence of thoughts, one at a time, in a sequence; we call this 'mental discourse', to distinguish it from discourse in words."

an actual train that travels the mind of the fictional character Riley Anderson, and delivers daydreams, facts, opinions, and memories.

A 'line of reasoning' might be seen as a strengthening of this blend, where the imposed PATH is linear. Although a 'line', mathematically speaking, has no beginning nor end, the way this expression is normally understood is as a discrete succession of arguments, following logical rules, leading to an insight or truth. Therefore, this blend might be analysed to correspond to the SOURCE_PATH_GOAL as described by Lakoff and Núñez [2000], in which there are both a clear path and a defined trajectory of the 'thought' (the trajector).

In order to understand how blending can result in these concepts, and how image schemas are involved, a closer look at the input spaces and their relationship to the PATH-following image schemas will be presented. Relevant input spaces include line (perhaps analysed as 'discrete interval'), stream/river, train/locomotive, and, as secondary input space, 'thinking process'.

'Thinking' as an input space is difficult to visualise. However, when 'thinking' is understood as a process it can be easily combined with various PATH-following notions. As thoughts (in the form of OBJECT) are moved around, the simplest form of thinking is MOVEMENT_OF_OBJECT. There is no START_PATH nor an END_PATH. Intuitively, it does not appear to have any particular PATH (in the sense of a spatial primitive).

A stream is characterised by a continuous flow along a PATH. Whilst a START_PATH and END_PATH can be part of a stream-like concept, like in the fleshed out concept of a river with a source and mouth, they do not constitute an essential part of the concept of a stream.

For a train (understood as 'locomotive'), the concepts of a START_PATH and END_PATH have a much higher significance. The affordances found in trains are primarily those concerning going from one place to another. A train ride can also be seen as a discrete movement in the sense that for most train rides, there are more stops than the final destination. This results in a discrete form of the image schema SOURCE_PATH_VIA_GOAL.

When blending such forms of movement with the thinking process, what happens is that the unspecified form of movement found in 'thinking process' is specialised to the PATH-following characteristics found in the second input space. The result is the conceptual metaphors for the different modes of thinking listed above, where the generic space contains just MOVEMENT_OF_OBJECT and the blended concepts inherit the more complex PATH-following from 'train', 'stream', or 'line'.

In more detail, Figure 6.10 shows two specialisations of the basic

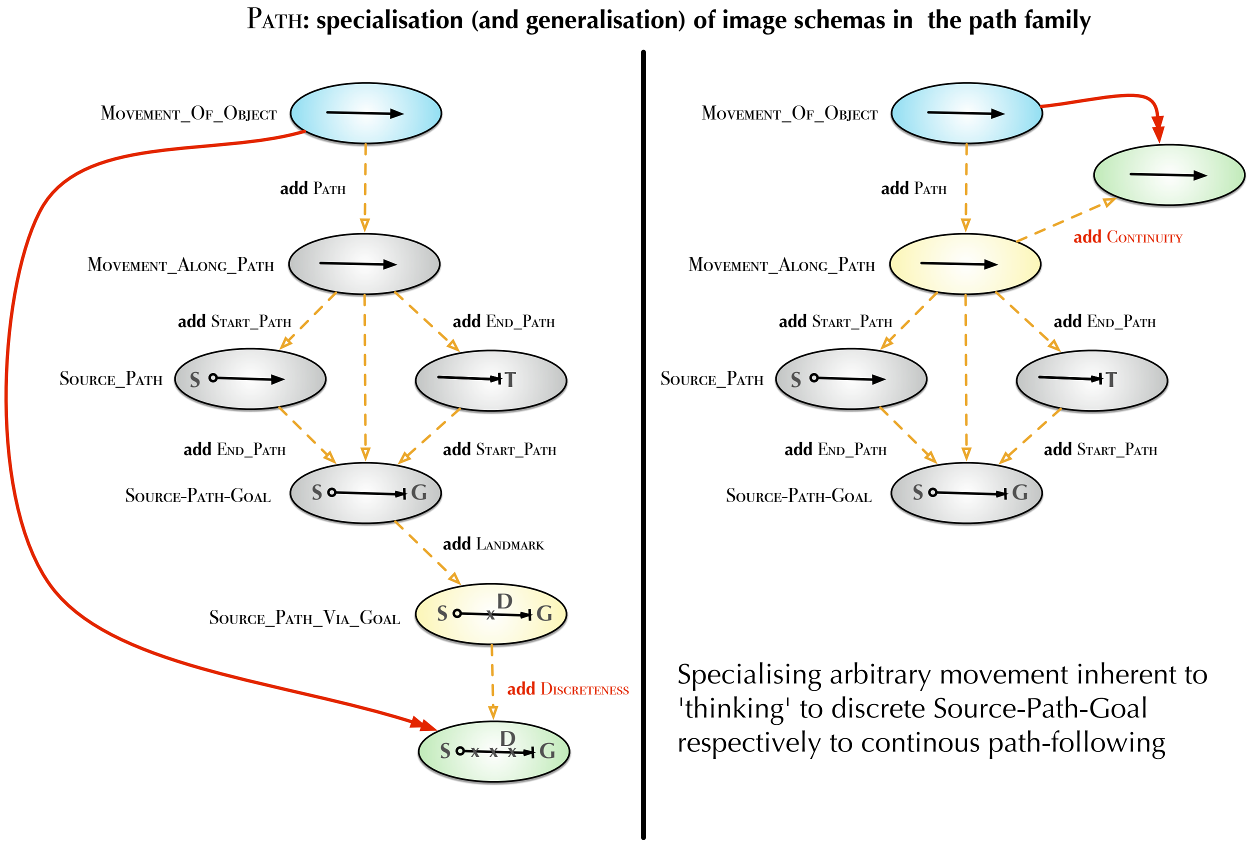

Figure 6.10: How 'thinking' transforms into 'train of thought' respectively 'stream of consciousness'.

image schema of MOVEMENT_OF_OBJECT. The first, shown on the left, specialises to a discrete version of the schema SOURCE_PATH_-GOAL with a designated element and discrete movement, supporting the 'train of thought' blend. The second, shown on the right, specialises in a continuous version of MOVEMENT_ALONG_PATH, where an specialisation for gapless movement is added to the MOVEMENT_-ALONG_PATH image schema to support the 'flow of consciousness' blend. As a third possibility, in 'line of reasoning', would be to impose additionally a linear (and perhaps discrete) path onto 'thinking'.

6.6 *Chapter Conclusion*

This chapter discussed how formalised image schemas can be used in computational concept invention through the framework of conceptual blending. This was done by looking closer at how image schemas structure the conceptual skeleton for similes and conceptual metaphors and how this could be translated into computational conceptual blending.

Regarding the integration of image schemas into conceptual blending, two different methods were highlighted. First, a method in which the image schemas should have higher priority as being inherited in the blend. Second, following the invariance principle, that the image schemas could be the foundation for the generic space/base ontology.

Simultaneously, suggestions on how to integrate the family hierarchy into the blending framework were formally introduced as both strengthening and weakening of the input spaces. This was illustrated through a series of examples.

7

Defining Concepts: Experiment on the Role of Image Schemas in Object Conceptualisation

Content and Context

> What is real is not the external form, but the essence of things... It is impossible for anyone to express anything essentially real by imitating its exterior surface.
>
> Constantin Brancusi
> *The Essence of Things, 2004*

Chapter 5 introduced the idea that combinations of image schemas represent the underlying conceptualisations of temporally complex image schemas and simple events. Likewise, Chapter 6 relied on the idea that concepts could be partly defined by their involved image schemas. In this chapter, these ideas are further investigated empirically by presenting an experimental study that investigates the image schemas behind a series of common objects.

7.1 *Image Schemas Behind Conceptualisations*

In chapter 5 the role of image schemas in event conceptualisation was investigated formally. This idea can be stretched further by backtracking from the complex conceptualisation of events to objects and concepts in the first place.

For instance, Kuhn [2007] proposed that the concept underlying the term 'transportation' can be described just considering the behaviour of the two image schemas Containment and Source_Path_Goal. Likewise, abstract concepts such as 'marriage' could, in a limited sense, be described using a combination of the image schemas Link and Source_Path_Goal, as a common conceptualisation of marriage is that of two 'parts' moving together on the axis of time [1].

So far, to the best of the author's knowledge, little empirical work has been devoted to identifying to which degree image schemas truly are the conceptual building blocks for everyday concepts. Therefore, this chapter contains an experimental study that investigates the relationship between a series of image schemas and the conceptualisation of everyday objects.

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[1] Jean M. Mandler. *The Foundations of Mind: Origins of Conceptual Thought: Origins of Conceptual Though*. Oxford University Press, New York, 2004

The experiment takes a closer look at a few commonly mentioned image schemas and their relationship to a series of everyday objects. The experimental set-up uses illustrations of eight of the most mentioned image schemas in the literature[2] to be used to describe a series of everyday objects.

7.1.1 *Related Work on Conceptualisation*

Classic work on conceptualisation is that of Kellman and Spelke [1983], who investigated infants' understanding of objects through a series of experiments on object occlusion. Their work shows that infants, already in the early months, understand the relationship between 'behind' and 'in front'. In terms of image schemas, their work demonstrated also that children at this early age have a conceptualisation of LINK as they can register that two parts moving in unison behind an occlusion belong to the same object.

A study that highlights the difference between concept definitions and conceptualisations is the work by Vinner [1983]. Vinner performed a survey with pupils in tenth and eleventh grade on their conceptualisation of mathematical functions. The work demonstrated how conceptualisations often varied more than the concept definition indicating a difference between the internal conceptualisation and the linguistic expression used to describe it.

Antović [2009] and Antović et al. [2013] performed experiments on music conceptualisation in relation to cognitive metaphor theory in different settings. Important findings were that musical concepts are often conceptualised by using visuospatial conceptual metaphors.

Looking directly at the link between conceptualisation and image schemas is among others the famous research by Lakoff and Núñez [2000]. In their book, they present theoretical support for the notion that image schemas lay the conceptual foundation for mathematical concepts. For instance, addition and subtraction are according to the authors perceived as movement along a path, an weaker form of SOURCE_PATH_GOAL. Also, Venn diagrams used to describe set-theory and discrete mathematics is a direct visual representation of the CONTAINMENT schema. Through their work, they make their way up to increasingly abstract concepts including tracing down the conceptualisation of 'infinity' and 'zero' into embodied experiences and image-schematic structures.

Looking at spatial categories for ontology building, Kuhn [2007] uses ontological properties of image schemas to formally construct concepts' underlying meanings. His work takes a straightforward approach to how image schemas can be used as conceptual building blocks for concept definitions.

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[2] Naturally it would be more accurate to present a complete list of all image schemas, however, two problems hinder this: First, there exists no coherent and agreed upon list of all the image schemas. Second, while by definition the image schemas must be of a limited number the current estimate is too vast to feasibly take part in an experiment of the nature proposed.

7.1.2 *Motivation and Hypotheses*

The main hypothesis that this chapter rests on is the notion that image schemas are conceptual building blocks that are used in conceptualisation for concepts.

Hypothesis I (H1): Image schemas are conceptual building blocks that capture the essence of concepts, including abstract ones.

Following this hypothesis it must be possible to investigate to which degree image schemas are involved in concept generation and understanding. This study challenges that hypothesis by looking at instances of everyday objects and their conceptual connection to the image schemas.

The purpose of the study was twofold. First, the desire to empirically establish if image-schematic thinking plays a pivotal role in conceptualising everyday objects. Second, if this was the case, then to establish if there are any differences of the importance of specific image schemas for different objects.

7.2 *Method*

7.2.1 *Material and Its Motivation*

Representing the Image Schemas: The first important obstacle was to select a feasible number of image schemas for the study. This presented two problems. First, which image schemas should be chosen given the large number of image-schematic structures proposed in the literature. Second, as image schemas are used to model abstract conceptual patterns, how can they be investigated in this study.

The selection was made on primarily two criteria. First, their commonality in the literature, with the motivation that the more commonly studied, the more reliable (or at least agreed upon) their image-schematic structure was. Second, the image schemas needed to be presented in such a way that it could be intuitively understood what the image schema entailed. This disqualified for thesee purposes the image schemas that are too abstract and dynamic rather than static.

The representation of the image schemas used two methods, consequently dividing the participants into two groups. First, simply the linguistic phrasing of the image schemas was used and, second, a basic visualisation of each image schema.

The visualisation of the image schemas was approached by aiming to inspire as much abstract thinking as possible. This resulted in a homogeneous design of all illustrations made with graphite pencil on white sketch paper. Figure 7.1 contains the visual illustrations of the eight selected image schemas.

After some contemplation, the following image schemas were selected: Blockage, Scale, Link, Source_Path_Goal, Support, Containment, Verticality and Cycle. Additionally, a 'none' alternative was also included to allow participants the choice of not assigning any image schemas.

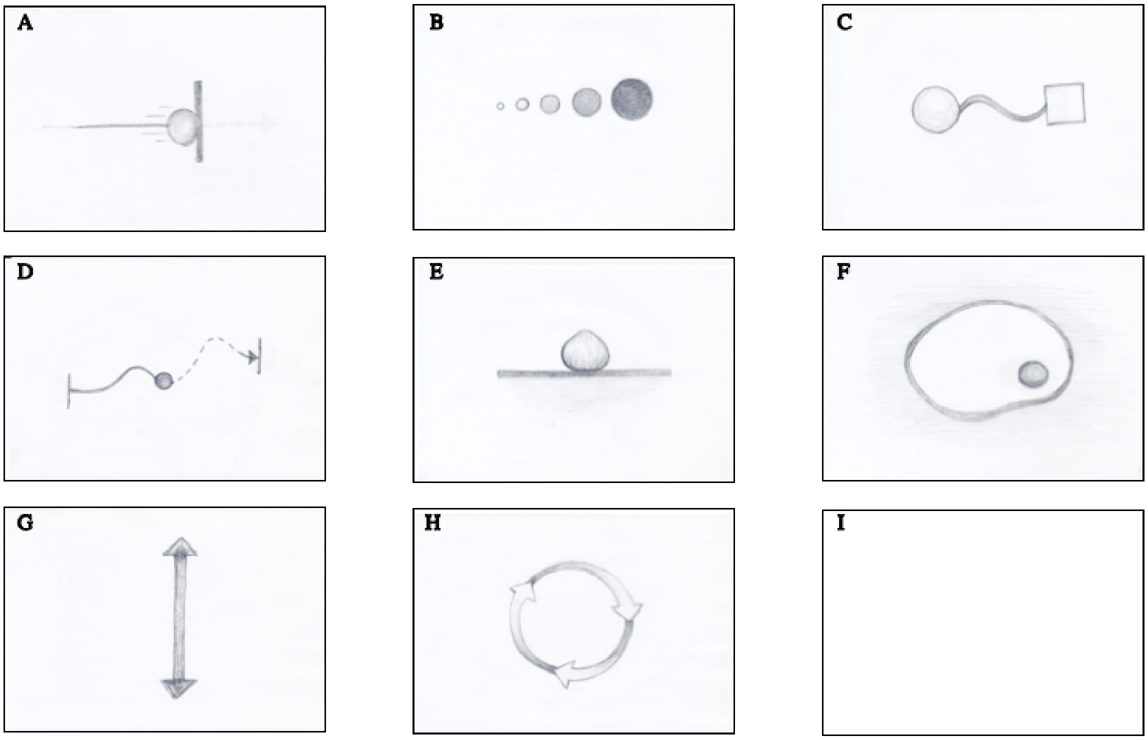

Figure 7.1: The image schema illustrations as used in the experiment. From $A - I$ as follows: *A*: Blockage; *B*: Scale; *C*: Link; *D*: Source_Path_Goal; *E*: Support; *F*: Containment; *G*: Verticality; *H*: Cycle; *I*: the empty set.

Everyday objects for assessment: While deciding which objects to choose, it was deemed important that they were objects that children come into contact with early on in conceptual development. This was believed to be important as the conceptual core of the concepts should be as sheltered from cultural influence as much as possible and instead represent a more basic conceptualisation. A second aspect was that in order to avoid priming the participants with language, the objects should be presented visually rather than written.

Therefore, flashcards for language learning were used[3].

Focusing solely on nouns, the selection process excluded all verbs and adjectives. Likewise, all animate objects, as well as roles, were eliminated as the association and conceptualisation to these categories may be clouded by personal and cultural experience. To get an as unbiased sample as possible, 44 objects were selected at random within the presented restrictions.

7.2.2 *Expert Assessment of the Objects Into Image Schema Categories*

Three image schema experts performed the experiment by assigning image schemas to the objects, generating a series of image schema categories.

Table 7.1 shows the objects after they have been sorted into their respective categories. Note that, occasionally, objects occur more than once as a consequence of the experts assigning multiple image schemas per object. The table is also missing three objects that were included in the experiment (camera, lamp, pacifier) since these had not been assigned any particular image schemas by the majority of the experts.

Table 7.1: The objects sorted into an image-schematic category by the majority of the experts.

Image schema category	**Objects**
VERTICALITY	colour pyramid, stiletto shoes, ladder, plant sprout, sunflower, skyscraper, stairs, tree
CYCLE	clock, screw, sunflower, washing machine
CONTAINMENT	banana, bathtub, boiled eggs, car, cherries, computer, guitar, hat, house, mirror, oven glove, pants, school bag, skyscraper, strainer, wardrobe, washing machine
SOURCE_PATH_GOAL	aeroplane, car, garden path, lightning, ruler, stairs, wheelbarrow
SUPPORT	bed, play blocks, chair, plate, stiletto shoes, sofa, wheelbarrow
LINK	ankle, cherries, computer, lightning, pliers
BLOCKAGE	oven glove, strainer, umbrella
SCALE	colour pyramid, fire, plant sprout, ruler, thermometer

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[3] Taken from `http://www.kids-pages.com`

7.2.3 *Participants and Experimental Groups*

The experiment consisted of 25 participants gathered using a convenience sampling. From these, four participants had to be eliminated due to not following the instructions of the experiment. The remaining 21 participants (females: 28.6 percent, males: 71.4 percent) had a varied cultural background, coming from twelve different mother tongues and ages ranging from 25 to 60 (*mean age:* 36.3, *median age:* 32, *SD:* 10.69, *variance:* 108.78).

As mentioned above, the participants were divided into two groups. Ten participants were presented with the illustrations of the image schemas (see Figure 7.1) and eleven participants were instead presented with the terms of the image schemas.

In order to avoid possibles bias towards particular image schemas based on placement on the sheets, each group was divided into an additional three groups, where the image schemas had been randomly re-arranged. Before all the data was analysed, this data was aligned to make sure that all answers were based on the same material.

7.2.4 *Experimental Set-up*

The experiment started with a brief oral introduction including encouraging the participants to carefully read the written instructions. Written instructions had been selected to avoid accidentally providing the participants with different instructions.

The experiment consisted of the participants to familiarize themselves with the alternatives $A - I$ on the image schema sheet, followed by flipping through the 44 flashcards[4] and to 'describe' the object on it by matching it to one or more of the abstract image schemas. They were explicitly asked not to focus on visual attributes of the illustrations nor of the objects, but instead to "think holistically about the object". The experiment also required the participants to write a short motivation to explain how they were thinking.

7.2.5 *Methods of Analysis*

Analysis of Method Behind Object Conceptualisation: The study aimed to investigate whether participants used image-schematic thinking to conceptualise the objects. To determine this, only the data in the motivations were used, as the assigned image schemas were considered irrelevant for the mode of thinking.

Presented below are the four major methods for analysis that were estimated to be at work when conceptualising the objects:

Image schemas: if the motivation contained the abstract spatiotem-

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[4] Note that the three objects excluded by the experts were still present in the experiment.

poral motion or relationship found in image schemas. Examples: Stiletto shoes: VERTICALITY and CONTAINMENT, *increase height of person, contain feet;*[5] Umbrella: BLOCKAGE, *blocks rain and sun*.

Association: if the motivation described associations to similar concepts and objects to that on the flashcard. Examples: Lightning: CYCLE, *the water cycle*; Ankle: SOURCE_PATH_GOAL, *running towards a goal*.

Visual/attribute cues: if the motivation made direct visual or attribute connections between the object and the image schemas. Examples: Camera: LINK, *objective is round, picture is square*; Boiled eggs: CONTAINMENT, *illustration looks like an omelette*.

Other: This was used when none of the previous methods were deemed applicable. Examples: Clock: BLOCKAGE, *if it falls it breaks*; Guitar: SUPPORT, *supports a singer*.

Analysis of Image Schemas Attributed to Objects: The second research question was to determine if it is possible to assign particular image schemas to certain objects. For this part, the data from both groups were merged, motivated by assuming that the illustrations and the terms could be treated equally. This was approached by, similarly to the expert assessment, generating image-schematic categories from the majority of the participants. At the same time, three other aspects were looked at more closely: First, the objects that had the highest assignment of 'nothing'; Second, the most consistently defined objects; And third, the objects that had more than 50 percent of a *particular combination* of assigned image schemas.

The objects that best matched these criteria were then presented and discussed to find the commonality amongst the objects that had the highest image-schematic structure.

7.3 Results

The results show a great diversity in the number of assigned image schemas between the participants. Some participants made an effort to find image schemas to all objects whereas other applied the 'nothing applies' answer more generously.

Likewise, despite having been made clear to the participants that they may choose to use more than one image schema to explain particular objects many participants chose to focus on the most prominent attribute and picked only on image schema. At the same time, there were participants who instead had the opposite approach with results that appeared to cover all possible aspects of the objects and therefore used a more generous assignment of image schemas.

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[5] Note the structure: IMAGE SCHEMA, *Motivation*

The group presented with illustrations were more inclined to select more than one image schema to describe the objects with an average of 1,41 assigned image schemas per object compared to the group presented with terms that had an average assignment of 1,22 image schemas per object.

7.3.1 *Assignment Method*

Table 7.2 shows the distribution in percent between the different assignments methods for respective participation groups.

Assignment method	**Illustrations**	**Terms**
Image schemas	70,82	65,48
Association	14,66	14,88
Visual/attribute cues	14,65	7,14
Other	10,23	12,50

Table 7.2: Distribution of method for assigning the image schemas to the objects for the two groups.

The results show a dominance in using a method of abstract image-schematic thinking when describing the everyday objects in approximately 2/3 of the time regardless of them being presented with illustrations or terms. This result gives a strong indication that the participants were thinking abstractly enough and in line with the goals of the experiment.

7.3.2 *The 'image-schematic' Structure of the Objects*

Image schema category	**Objects**
VERTICALITY	ladder, skyscraper, stairs, tree
CYCLE	clock, plant sprout, screw, washing machine
CONTAINMENT	bathtub, boiled eggs, house, school bag
SOURCE_PATH_GOAL	aeroplane, car, garden path
SUPPORT	bed, chair, sofa, wheelbarrow
LINK	computer
BLOCKAGE	
SCALE	ruler

Table 7.3: The objects sorted into image-schematic categories by at least 50 percent of the participants.

Mapping of Image Schema Group: Table 7.3 shows the image schema categories where at least 50 percent of the participants agreed upon a particular image schema for the same object. While the table demonstrates a great reduction in the number of assigned image schemas compared to those made by the experts (see Table 7.1), it does represent a near perfect mapping. Out of the objects that the participants agreed upon, all but one ('plant sprout') had been assigned the same image schemas by the experts, illustrating that while the participants had no prior knowledge of the concept of image schemas, their intuitions closely align with those of the experts.

The Highest Non-Assigned Objects: Whilst the experts could not find an agreement on three objects, this number was higher for the participants. The objects in Table 7.4 demonstrate the object with the highest number of 'no image schema' assigned.

Table 7.4: The objects that the participants found the hardest to describe in image schemas.

Count	Object	Count	Object
9	camera	6	pants
9	lamp	6	strainer
8	fire	5	blocks
8	hat	5	cherries
6	banana	5	mirror
6	guitar	5	pacifier
6	lightning	5	skyscraper
6	oven glove	5	umbrella

The Most Consistently Assigned Objects: After counting the number of assessed image schemas to each object and per person, a few objects ranked higher in agreement of the assigned image schema. Table 7.5 shows the objects that had at least 2/3 of the participant in agreeing in the assignment task.

Table 7.5: The objects in which more than 2/3 of the participants assigned the same image schemas.

Count	Object	Image schema
18	chair	SUPPORT
16	garden path	SOURCE_PATH_GOAL
16	sofa	SUPPORT
16	ladder	VERTICALITY
15	bathtub	SUPPORT
15	washing machine	CYCLE
14	stairs	VERTICALITY

The Image-Schematic Combination Objects For some objects, the pattern for assigning image schemas was spread widely amongst the different alternatives to assign image schemas. However, for several of the objects, the assigned image schemas arranged in patterns in which more than one image schema played a central role in its conceptual description. The objects which had two (or on one occasion, three) assigned image schemas that 'in combination' had been assigned by at least 50 percent of the participants, can be seen in Table 7.6.

Count	Object	Image schemas
8, 7, 6	wheelbarrow	SUPPORT, CONTAINMENT, SOURCE_PATH_GOAL
9, 8	sunflower	VERTICALITY, CYCLE
6, 6	stiletto shoes	SUPPORT, VERTICALITY
6, 5	play blocks	VERTICALITY, SUPPORT
6, 5	ankle	SUPPORT, LINK

Table 7.6: The objects which appear to be conceptualised as a combination of image schemas.

7.4 *Discussion*

7.4.1 *Method Discussion*

Sample: The participants were gathered through a convenience sampling. This resulted in a higher than average level of education of the participants, which in turn could have resulted in unintended 'over thinking'. However, since the experiment had the purpose to tap into the underlying conceptual structure, it is believed that the possible effects of this are minimal and that they can be disregarded.

Likewise, the gender distribution is uneven. However, since the experiment does not presume any gender difference in cognitive conceptualisation (supported by e.g. Richardson et al. [1997]) and the cognitive mechanisms investigated ought to not be influenced by any potentially existing gender-cultural differences, it is believed that this uneven distribution can be disregarded as well.

The divergence in nationality, consequently also in native language, and the varied age of the participants are thought to produce a fairly solid sample. Naturally, the sample size lies in the lower margin with only 21 participants whose performance could be counted into the analysis of the results. In order to properly assess the generalisability of the results, further studies need to be conducted.

Material: Regarding the image schema illustrations, the results illuminated a few issues with some of the them. The biggest challenge of making the illustrations was to capture the whole family of notions involved in the image schemas, meaning that CONTAINMENT should also include the notions of IN and OUT, and VERTICALITY should include vertical movement and/or relative position in either direction of UP-DOWN. Likewise, SOURCE_PATH_GOAL was required to cover not only movement but the source and the goal as well, supported by the family representation of image schemas presented in Chapter 3.

The experiment used a set-up with static illustrations, suppressing the dynamic aspects of the image schemas. To balance this issue, the instructions contained an explanatory text: *"The nine illustrations are meant as capturing a mental 'idea' and while this abstract content should remain you may perform transformations to apply it to the context of the object"*. However, it is not clear whether these clarifications were interpreted in the intended way. For instance, one of the participants violated the VERTICALITY principle by transforming it into 'horizontality', rather than preserving the verticality through other means of transformations.

Additionally, the results indicated that the image schema illustrations might have been a bit too abstract. The participant's written motivations occasionally demonstrated misapprehension to some of the illustrations, where LINK was the illustration to gain the most incoherent interpretations. Naturally, this had negative effects on the results, producing outliers.

For further and similar experiments, the image schema illustrations presented in this study may be used as a guide, but ought to be mildly modified in order to better capture the dynamics of the underlying spatiotemporal relationships.

As previously motivated, the objects had been chosen because of their commonality in everyday life, varying from simple (e.g. chair, house) objects to increasingly complex objects (e.g. camera, washing machine). Their visual representation utilised pre-designed flashcards to have a homogeneous design. The goal of choosing objects with a coherent visual representation was to lower the possible problems due to participants being distracted and associate the objects on the cards with particular visual characteristics. While most of the pictures caused no misapprehension in the subjects, two of the illustrations appeared to have been borderline cases: the 'skyscraper', to which several participants asked what the picture portrayed, and the 'ankle' which some participants (as illuminated in the participants' motivation) had interpreted as a 'foot'.

7.4.2 *Result Discussion*

Method Behind Object Conceptualisation: With approximately 2/3 of the image schema assignments determined through abstract image-schematic thinking, the result provides strong support towards objects being conceptualised in accordance with the main hypothesis of this experiment, namely that image schemas lie at the foundation and give structure to the meaning of concepts [6,7].

The findings show similar results as those found in the related work on music conceptualisation and image-schematic structures

[6] Mark Johnson. *The Body in the Mind: The Bodily Basis of Meaning, Imagination, and Reason*. University of Chicago Press, 1987

[7] George Lakoff. *Women, Fire, and Dangerous Things. What Categories Reveal about the Mind*. University of Chicago Press, 1987

performed by Antović et al. [2013], who showed that music conceptualisation is often based on visuospatial metaphors.

Image Schemas Assigned to Objects: The results show a near perfect correlation between the expert assessment (taken as a golden standard) and the most commonly assigned image schemas per object. While the experts demonstrated a superior level of detail in terms of which image schemas were assigned, among the objects where the majority of the participants assigned the same image schema, there was only one instance that did not correspond to the experts' choice. While this is an encouraging result underpinning that image schemas can be seen as conceptual building blocks, the rather large variance in choices needs attention. One reason for this might be due to the image schemas not being comprehended completely. A second reason could also lie in the observed high reluctance among the participants to assign more than one image schema per object. Naturally, this resulted in a smaller set of image schemas to be distributed over the objects than in the more generously assigned image schemas found among the experts.

Regarding why some objects had a higher number of 'no image schema assigned' might have been a consequence of the objects being perceived as more complex. For example, the underlying conceptualisation of an object such as a 'camera' might be far more affected by associations and the 'complex' usage than objects far more straightforward such as a 'chair'. Indeed, the complex technical artefacts had low image-schematic content also in the expert assessment. Perhaps it is no longer appropriate to speak of objects such as these as image-schematic alone, after all, they are also concepts that humans usually fail to comprehend in early childhood, but rather are learned through life-experience and cultural exposure.

Likewise, objects such as 'banana' and 'cherries' whose primary function (for humans) is to be eaten may also not carry clear image-schematic content in terms of spatiotemporal relationships as used in this study, but rather have other affordance-based conceptual primitives associated, relating to nutrition and providing physical energy[8].

The objects that were most coherently assigned image schemas were those objects where the usage of the object, and people's contextual experience, are more or less homogeneous amongst individuals. The possible uses and experiences a person has with a 'chair' are more or less identical in all (adult) individuals. Likewise, different modes of transportation are heavily associated with the notion of going from one place to another; therefore, concepts such as car, aeroplane and garden path naturally are associated to the SOURCE_-PATH_GOAL schema in accordance with the ideas presented by Kuhn

[8] In accordance with embodied cognition and the multi-modal nature of image schemas, it is possible that primitives such as those found in taste and bodily reactions to food should also be included in the research field of image schemas. However, to my knowledge, little such research exists as of yet.

[2007].

7.5 *Chapter Conclusion*

The notion of 'image schema' is central to conceptual metaphor theory, has been an influential idea in cognitive linguistics for decades and is increasingly being used in cognitive AI approaches. This study has provided empirical support that strengthen the hypothesis (H1) that image schemas can serve as core conceptual building blocks for everyday objects. With this in mind, the study investigated different aspects of image schemas in object conceptualisation for the purpose of identifying general patterns in conceptualisation and their relationships to image schemas.

The first research question addressed to which degree abstract conceptualisations can be considered to be based on image-schematic thinking. The results of this study show that for the variables used in this study, roughly 2/3 of the participants' conceptualisations were based on the abstract nature found in the spatiotemporal relationships captured by image schemas. This gives good grounds for the experiment and suggests that image schemas are involved in the conceptualisation of object.

The second research purpose was to determine whether some objects are thought to be more image-schematic than others. The results provide support for that this is indeed the case. It can be argued that the differences found may depend on socio-cultural influences associated with the objects, as the more complex objects often were more inconsistently assessed, and objects with more straightforward affordances associate with it (e.g. 'chair' which affords 'sit_on' associate with the image schema SUPPORT) had higher consistency in assigned image schemas.

In summary, one conclusion to be drawn from the study is that the investigation of image schemas as conceptual building blocks is a promising research program to tap into cognitive mechanisms behind conceptualisation.

Future work will have to confirm the findings in more refined set-ups, extend the approach to dynamic presentations of image schemas, and address the multi-modality of image-schemas beyond the basic spatiotemporal interpretation.

8

Identifying Image Schemas: Experiment Towards Automatic Image Schema Extraction

To understand is to perceive patterns.

Isaiah Berlin
The proper study of mankind: an anthology of essays, 1997

Content and Context

One of the missing pieces before image schemas can be used in conceptual blending and artificial intelligence is a method to automatically identify image schemas in natural language. In order to investigate this problem, the Path-following family introduced in Chapter 3 will be empirically investigated by using a natural language corpus to detect existing members of the family and detect possible additional candidates. The experiment relies on a method of syntactic pattern matching using words strongly associated with movement and processes. The experiment includes four different languages to strengthen the idea that Path-following in abstract domains (here finance) is not only found in one language but universal as assumed through their embodied manifestation. The experiment found that approximately 1/3 of extracted words could be image-schematic and could not only provide linguistic support for the members of the Path family but also provide additional candidates.

8.1 *Challenges with Image Schema Identification*

One of the most challenging parts of using image schemas in formal systems and artificial intelligence is that it currently exists no comprehensive method to identify them in natural language. If image schemas are to be used in systems dealing with natural language understanding or production, as seen with conceptual blending in Chapter 6, then there needs to exist a method to automatically identify the image schemas in natural language, both in expressions that are concrete and abstract. Additionally, by automatically identifying image schemas in natural language it would be possible to expand the number of identified image schemas and place them in their respective family as presented in Chapter 3. As there currently exists no agreed-upon list of the image schemas, any method that extracts image schemas would greatly help to build a better comprehension as to which image-schematic entities exist in natural language.

The main purpose of the experiment is to approach this problem by trying to device a method that can find empirical support for the ideas presented in Chapter 3, in particular regarding the hierarchy of the PATH family.

8.1.1 *Motivation and Hypotheses*

Detecting spatiotemporal relations in natural language is central to a wide range of Artificial Intelligence (AI) applications, including robotic navigation (e.g. Tellex et al. [2011]), manipulation instructions in human-robot interaction (e.g. Misra et al. [2016], Kollar et al. [2014]), simulation of natural sensorimotor knowledge acquisition of infants (e.g. Guerin [2008]), and any kind of mapping between natural language symbols and their objects in the physical world (e.g. Krishnamurthy and Kollar [2013]). However, the symbol grounding problem, introduced in Chapter 1, remains challenging. The cognitive grounding of spatial language has been investigated in different disciplines, including AI [1] and linguistics [2].

This chapter rests on the assumption that any mental conceptual system guiding abstract thinking and acting in humans is also the system that communication is based on. Natural language is considered "an important source of evidence of what that system is like" [3], referring to the cognitive system guiding our actions.

The experiment rests on the hypothesis discussed in previous chapters, namely:

Hypothesis I (H1): Image schemas are conceptual building blocks that capture the essence of concepts, including abstract ones.[4]

Hypothesis II (H2): Following from H1, Image schemas are consistent over languages as the meaning of concepts is consistent over languages.

8.2 *Method*

The method builds on the ontology of the PATH-following family introduced and developed in Chapter 3 and Chapter 4, where linguistic manifestations of image-schematic structures were one of the grounds for differentiating between the members of the family. The experiment extracted potential candidate entries for the PATH schema in English by means of lexico-syntactic patterns and synonym sets.

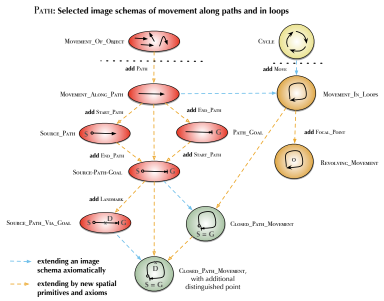

Figure 8.1: The PATH-following family from Chapter 3, see Page 3.3.

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[1] Dipendra K. Misra, Jaeyong Sung, Kevin Lee, and Ashutosh Saxena. Tell me dave: Context-sensitive grounding of natural language to manipulation instructions. *The International Journal of Robotics Research*, 35(1-3):281–300, 2016

[2] Beate Hampe and Joseph E. Grady. *From perception to meaning: Image schemas in cognitive linguistics*, volume 29 of *Cognitive Linguistics Research*. Walter de Gruyter, Berlin, 2005

[3] George Lakoff and Mark Johnson. *Metaphors We Live By*. University of Chicago Press, 1980

[4] Note that this is the same hypothesis as in Chapter 7.

Additionally, this was done for German, Swedish and Italian, as the used natural language corpus consists of multilingual alignment of terminological data. The results were manually analysed by first language speakers to map them to the different PATH schemas. The analysis used the structure of the PATH-following ontology (see Figure 3.3 or 8.1 for a smaller version) as well as a graphical representation method.

8.2.1 *The Corpus: A Financial Terminological Database*

Concept-oriented terminological databases organise multilingual natural language data into terminological entries, so-called 'units of meaning'. A terminology seeks to mitigate ambiguity and polysemy of natural language by limiting its content to a specialised domain of discourse. The use of a given term is specified by means of its salient features and semantic type in a natural language definition. All natural language descriptions associated with the same entry are considered semantically equivalent. Such resources are typically applied to computer-aided translation, information extraction, machine translation, corporate terminology management to name a few.

The data set for this experiment was extracted from the InterActive Terminology for Europe (IATE)[5], which classifies its 1.3 million entries in up to 24 European languages by domain and sub-domain. For this experiment, only entries classified into the financial domain and its sub-domains were considered. Likewise, the search was limited to the extraction of entries that existed in all the following languages: English, Swedish, German, and Italian.

8.2.2 *Lexico-Syntactic Patterns and Entry Extraction*

In order to identify the image schemas, lexico syntactic patterns were used to identify the spatiotemporal relationships. Inspired by the method presented in [Bennett and Cialone, 2014], in which CONTAINMENT was sought for through identification of similar words (e.g. enclose, surround, contain), a series of PATH related words (see Table 8.1) were used to automatically identify members of the PATH family.

The lexico-syntactic patterns were initially motivated by the presented members of the PATH-following family, with abstract interpretation to some of the more complex members such as CYCLE and MOVEMENT_IN_LOOPS. Likewise, attention was given to the spatial primitives such as SOURCE and GOAL presented by Mandler and Cánovas [2014] in order to identify the difference between image schema members such as SOURCE_PATH_GOAL, PATH_GOAL and SOURCE_PATH etc. In consequence, this meant that words such as

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[5] Taken from `http://iate.europa.eu/`.

Table 8.1: Lexico-Syntactic Patterns for PATH Extractions

Pattern name	Content
From-to	from [...] to
Prepositions	around, across, through, behind, before, earlier
Movement	movement, track, path, transportation, transit, mobility, steps, passage
Process	process, operation, transfer, transferal
Development	development, evolution, progress, progress, progression, chance, migration
Cycle	cycle, course, chain, ring, rotation, circle, circuit, loop, sequel, orbit, wheel
Move	move, transfer, drift, migrate, walk, drive, fly, proceed, etc.
Start	start, commence, begin, etc.
End	end, target, arrive, etc.

'from' and 'to' were included in the sought for patterns.

8.2.3 *Linguistic Mapping of Image-Schematic Structure*

The mapping procedure was made on the pattern-extracted entries per language. For each language, one (German, Swedish) or two native/fluent speakers (English, Italian) mapped the concept to the image-schematic structures. The method consisted of mapping the definition of terms to the PATH-family. This was done through using a graphical representation technique that aimed to take the linguistic expression to a more concrete spatiotemporal representation in order to assign the potential candidates the right member of the PATH family. While following the general structure of the family, additional image-schematic components where considered in order to not only strengthen the PATH-family notion but also by analysis improve the PATH-family to match natural language. This allowed for a freer interpretation of the terms which better mapped the intended content. At the end, a comparison of all identified schemas allowed for an evaluation of their cross-lingual persistence.

8.3 *Results*

The analysis targeted the identification of image-schematic structures of PATH-following in natural language text across four natural languages. The (a)symmetries of such structures across languages were of particular interest as well as the coverage of the predefined schematic structures (see Figure 3.3) within the domain of financial terminology.

From the financial subset of the IATE terminology database, the extraction was restricted to entries containing natural language definitions and a minimum of one of the identified patterns. Thereby, 190 extracted terminological entries for the languages English, Swedish, German, and Italian were obtained. A manual analysis of at least one first language/fluent speaker per language resulted in more than 69 entries or 36 percent containing image-schematic structures related to Path-following. This was followed by breaking down the results into individual languages through individual interpretation. Here 224 schema structures or 31 percent could be identified from the 720 natural language definitions across the four languages. The results separated by language and structure are depicted in Table 8.2 as cumulative frequencies. A majority of extracted entries could be discarded as objects, institutions, natural or legal persons, strategies, techniques, or measures, that is, not related to any kind of Path or movement. Instead, events, processes, and actions provided excellent candidates for image-schematic structures within a Path family.

Image-Schematic Structure	**Eng**	**Swe**	**Ger**	**Ita**	**Total**
Link	2	4	2	2	10
Source_Path_Goal (SPG)	3	7	6	7	23
Source_Path	7	6	7	11	31
Path_Goal	6	9	10	7	32
Source_Path_Via_Goal (SPVG)	3	2	3	1	9
Path_Via_Goal *	2	1		2	5
Source_Path_Via *	1				1
Caused_Movement	1				1
Closed_Path_Movement	2		1	1	4
Movement_In_Loops	1	1	1	1	4
Path_Switching *	1		1	1	3
Jumping *	1	1			2
Blockage_Avoidance *	1		1	1	3
Path_Splitting *	4	3	4	3	14
SPG and SPG	1	1	1	1	4
SPVG and SPVG	1	1	1	1	4
SPG OR Path_Splitting		1			1
SPG OR Path			1		1
SPG OR Link	1	1	1	1	4
Total	**57**	**54**	**58**	**54**	**224**

Table 8.2: Metrics for identified image-schematic structures across languages. * indicate novel finds that were not previously introduced in Chapter 3. 'and' is the presence of more than one image schema and 'or' determine a distinct uncertainty.

8.3.1 Statistical Results of Patterns

With just above 30 percent the overall precision of the extraction and analysis method is rather low. This means that only 1/3 of the overall extracted entries actually contained image-schematic structures from the PATH schema. Judging from the number of identified image schemas for each pattern, nominal structures and prepositions returned most candidate entries. A total of 67 percent of the 'CYCLE' synonym set and 59 percent of the 'process' nouns returned image-schematic structures, followed by 'from-to' with 40 percent of the 48 extracted entries. The 37 extracted entries based on prepositions (across, through, around, etc.) and the 7 ones based on motion verbs resulted in image schema candidates in 30 percent of their cases. The 'end' pattern with 8 entries contained one schema, 'start' with 3 potential schemas provided no schemas at all. While the movement and development pattern extracted almost 20 entries each, only 19 percent in the former and 18 percent in the latter case contained PATH-related structures.

8.3.2 Image Schema Candidates

All resulting image-schematic structures are ordered by approximated complexity in Table 8.2. Financial entries in the data set most frequently (30 percent of all cases) feature a regular SOURCE_PATH_-GOAL schema followed by the similar, yet simpler, pattern PATH_-GOAL. On occasion, specific textual references concurrently defined two image-schematic structures that could equally be designated by the same given term. For such cases representation with the logical operator 'OR' was opted for. For instance, an 'interlinking mechanism' (IATE:892281) can designate a cross-border payment procedure 'OR' a technical infrastructure, which was represented as SOURCE_-PATH_GOAL 'OR' LINK.

8.3.3 Breaking Down the CLOSED_PATH_MOVEMENT *Schema*

A graphical representation technique was employed to identify the movements of objects between entities along PATHS for each definition in each language. It turned out that some of the identified image-schematic structures were not present in the predefined structures in Figure 3.3. From all languages, four different scenarios depicted in Figure 8.3 could be identified by means of the graphical representation technique. Additionally, image-schematic structures of a 'double-way' SOURCE_PATH_GOAL movement could be observed in financial definitions. These movements were dependent on two variables: the number of PATHS and the number of OBJECTS that are moved along them. The four resulting image-schematic structures that are differentiated based on those two variables are depicted in Figure 8.2.

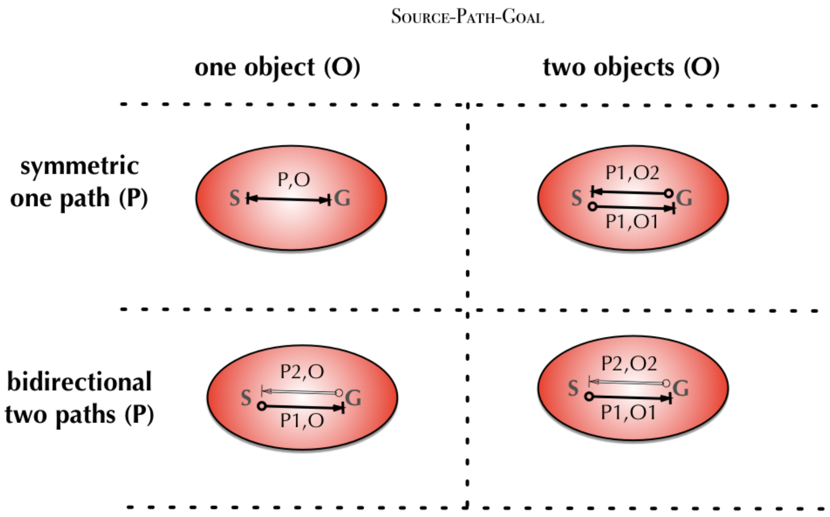

Figure 8.2: The Returning Object(s) Problem

In a symmetric Source_Path_Goal, one Object moves or is being moved along one path until it returns to its starting point, potentially also passing a distinguished point. For instance, taking out and repaying a loan is the transfer of money from the creditor to the debtor where the same object (money) is returned on the same Path (e.g. bank transfer) to the original source, that is, the creditor. In cases such as this, the Source and the Goal coincide, and the concept matches the Closed_Path_Movement introduced in Chapter 3.

It is also possible, however, that the Path of returning differs from the initial one, in which case the image-schematic structure specifies two Paths. If the same Object moves from the Source and back again on a different Path, this is introduced as a bidirectional Source_Path_Goal. In the event of Source and Goal being identical, the Path that returns to the Source can either be equivalent to the initial Path (symmetric) or differ from the original Path (bidirectional). The latter would be considered a bidirectional Closed_Path_Movement. For instance, 'painting the tape' (IATE: 927775) is an example of several transactions (Paths) being used in a Closed_Path_Movement to create the impression of price movement of a financial instrument.

A second dimension that was identified is whether the returning/exchanging Object is identical to the first one. In finance, often the returning object is different from the one initially moved along the Path, basically capturing any kind of exchange or purchase. The Source for one object becomes the Goal for the second object and vice versa. The two different Objects moving along the same path are defined as poly-object symmetric Source_Path_Goal. If two Objects move along two different Paths, this is called call this a poly-object bidirectional Source_Path_Goal. A real-life example is the exchange of shares (the first Object) from the stock market (the first Path) and money (the second Object) from a bank transaction (the returning Path) between a client and a broker.

8.3.4 *Additionally Identified* Path *Members*

Additionally, four Path-related structures that did not appear in Figure 3.3 and Chapter 3, could be identified. These four structures are Jumping, Path_Switching, Path_Splitting, and Blockage_Avoidance[6]. As they did not already appear in Chapter 3, it can be argued that the Path family can be extended by these additions. In Figure 8.3 they are depicted. Note that the illustration of Blockage only serves the sole purpose to clarify the movement involved in Blockage_Avoidance.

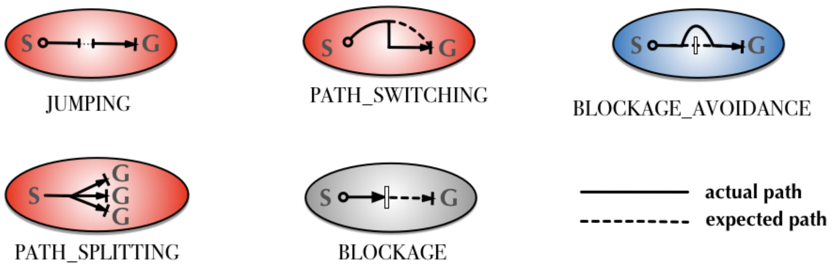

Figure 8.3: Four kinds of complex PATH structures extracted from the financial domain

Jumping: First, Jumping[7] represents the temporary discontinuity of a given Path. For instance, 'bond washing' (IATE:3544441) is a method of obtaining tax-free capital profits by selling the bond immediately before the coupon pays and buying it back right thereafter to avoid tax payments. 'Bond washing' is a classic metaphor based on the notion of 'cleaning', which indeed capture important aspects of the term. However, while explaining the underlying process behind the term also the Path-following family can be used. Considering ownership as the Path from the initial acquisition of the bond (Source) to the gains it generates (Goal), 'bond washing' leads to this interruption of the Path and can be seen as an example of Jumping. The term is taken from the equivalent physical movement that makes the object temporarily lose touch with the path and inevitably

[6] Note that these members are written in the image schematic caps despite them previously not being introduced as image schemas. This is an active choice as they are here introduced as image schema candidates in the Path family, not as spatial or conceptual primitives.

[7] Jumping is not to be confused with the motion verb *to jump*. It refers to a jump in time or space, much like 'teleportation' rather than a temporary elevation.

leads back to the same path subsequent to the discontinuation, i.e., the jump. While it may be argued that JUMPING is simply a sequential combination of two disjoint SOURCE_PATH_GOALS, JUMPING takes on its own logic as both paths are involved in one particular movement as demonstrated in the conceptualisation example above. Therefore, it can be argued that JUMPING can be justified as a complex image-schematic structure in its own right much like BOUNCING was argued for in Chapter 5.

PATH_SPLITTING*:* Second, in case of PATH_SPLITTING, one object is distributed along a path to several GOALS. It could be argued that this represents merely a type of cardinality. However, since the PATH can be asymmetrical or bidirectional, it can be considered an image-schematic structure in its own right. For instance, in all kinds of 'tender procedures' (e.g. IATE:887199) the identical piece of information (a call) is sent to several parties, who return their individual pieces of information (the bids). Hence, this is an example of bidirectional PATH_SPLITTING. One example to account for this image-schematic structure in sensory-motor experiences would be the distribution of auditory information to several recipients with varying replies.

PATH_SWITCHING*:* Third, in PATH_SWITCHING the expected PATH is fully discontinued and replaced by a new PATH. For instance, the definition of 'refinancing' (IATE:786103) specifies the extending of a new loan and a mutual agreement to discontinue the previous loan. Thus, the original loan PATH is switched to a new loan PATH with altered conditions. It is important to note that the definition clearly specifies the replacement of a debt obligation with a new one and not merely altering the conditions of an existing loan. This explicit switching of the agreed path is an excellent example of PATH_SWITCHING.

BLOCKAGE_AVOIDANCE*:* Finally, the active avoidance of a BLOCKAGE can be considered an image-schematic construction that combines a number of pre-existing structures and schemas. The course of the PATH is (intentionally) altered to prevent the discontinuation of the movement of the object due to a BLOCKAGE. A 'Paulian action' (IATE:822870) allows a creditor to take action to avoid potential fraudulent activities of an insolvent debtor, granting the former rights to have a debtor's transaction to that end reversed. Thus, the term as such represents an example of BLOCKAGE_AVOIDANCE.

8.3.5 Image Schemas Across Languages

A slight asymmetry in the distribution of image-schematic structures across languages could be observed. In English and German definitions more structures could be identified than in Swedish and Italian, as shown in Table 8.2. However, those statistical results fail to provide any insights into the differences across languages. In a surprisingly high 45 percent of all 69 entries, the identified schemas were not identical across the languages. However, it has to be taken into consideration that in 27 percent of all cases the differences arise from either an addition or omission of a Source, Goal, or VIA, while the general structure is that of a Source_Path_Goal. Differences that arise from other sources can be pinned down to 10 percent of all entries. A slight preference of Goal usage in Swedish and German could be observed as opposed to a heightened use of Source in Italian in the reduced Source_Path_Goals.

The method deliberately relied exclusively on explicitly described content. This means that omissions that arise from linguistic or grammatical differences across languages or stylistic choices affected the extraction result. For instance, differences can arise from a heightened use of passive constructions in one language, e.g. German, and an increased utilisation of active Sources and Goals due to grammatical choices in another. One of the reasons for this choice was the intention to analyse linguistic consistency in relation to schematic persistence across languages.

In a final cross-lingual analysis, it was found that most cross-lingual differences in the identification of schematic structures arise from unnecessarily complicated descriptions, or even inconsistencies, in one language. Semantically identical entries resulted in diverging image schemas for two major reasons: a) the difference in lexical or grammatical choices (e.g. passive vs. active voice), and b) the omission of salient features. While the first difference postulates no difficulty for human users, the second severely distorts the term's understanding for users of that language. For automated methods, both differences lead to a certain degree of difficulty. The method could uncover inconsistencies across languages for both cases, which was considered an added benefit of the linguistic mapping of image schemas.

This approach equally uncovered conceptual inconsistencies across and within languages. For instance, 'equity capital' and 'equity financing' (IATE: 1119090) are modelled as synonymous where in fact the former refers to equity of the company while financing refers to the process of generating such capital. Thus, they should clearly be separated into two entries, a claim that is supported by the fact that the entry's definition consists of two sentences that define both concepts. In view of potentially automating the approach, it was found that a linguistic analysis of the specification's surface structure would definitely lead to misleading results. For instance, 'lifecycling' (IATE: 3516328) describes a shift of a person's investment approach at a specific moment in life rather than a CYCLE as the term suggests. Furthermore, the manual approach and cross-linguistic analysis revealed (unintentionally) repeated definitions and entries, e.g. 'fine-tuning operation' (IATE: 111402 & 907147).

8.4 Discussion

One of the most important parts of the used method was the extraction of terms and definitions. This was achieved by applying a limited number of lexico-syntactic patterns to the English definitions of terms. The initial patterns resulted in more than 3000 extracted entries that at first analysis contained less image-schematic structures than what had been expected and desired. A repeated tweaking of the patterns reduced this number to 190 pattern-extracted entries with a precision of only one third. This was partly due to the entries mostly referring to actual objects, such as financial instruments or institutions, rather than processes or events, which was one criterion for the entries to be regarded as a candidate for image schemas. For further experiments, precision of the applied patterns needs to be improved.

A second problem that was disregarded, is the recall of the applied extraction method, that is, the number of potentially missed schemas. It is unlikely that a rich database like the one used for this study should result in so few image-schematic structures. It would be advisable for future replications of the study to make sure that the extraction patterns have a better coverage and higher precision. In fact, the exact choice of patterns and linguistic expressions used for the extraction have a strong influence on the nature of schemas that might be obtained [8]. Thus, the extraction method is biased by the choice of vocabulary and the linguistic structures opted for. Naturally, the method also has a strong English bias, since this initial experiment was limited to the extraction of the English definitions and benefited from the multilingual alignment of entries in the database. These biases could definitely be reduced by the cross-linguistic application of abstract lexico-syntactic patterns or even an altogether different approach to information extraction, such as machine learning.

Another issue is the method applied for the analysis. In this study, it was performed by one or two individual(s) fluent in the language.

[8] Laura Lakusta and Barbara Landau. Starting at the end: The importance of goals in spatial language. *Cognition*, 96 (1):1–33, 2005

Naturally, this did not represent a particularly large sample and consequently, both potential errors and biases are problems. Although the basic criteria for definitions as specified, qualifying as image-schematic structures, the final decision might be subjectively biased due to the low number of judges. Due to that limited number of experts, it was also not possible to provide an inter-rater agreement. However, an evaluation of the quality of the schema identification process was conducted by means of the final cross-lingual comparison, which made for re-evaluation each individual schema candidate in each language. One way to improve on these issues is to have a larger sample of analysts that perform the image-schematic mapping. This should primarily be a method to obtain a gold standard as at the same time a stronger level of automation for the actual method is needed.

A clear preference for the SOURCE_PATH_GOAL together with SOURCE_PATH and PATH_GOAL schema could be observed in all languages. Mandler and Cánovas [2014] claims that PATH_GOAL is more important and more prevalent in the (pre-linguistic) usage of schemas by adults and children, an argument supported by the findings of Lakusta and Landau [2005]. They presumed that children do not require SOURCES to conceptualise a PATH_GOAL, which is why it is often omitted in cross-lingual analyses of image schemas. This experiment could not provide strong evidence for or against this claim as both SOURCE_PATH and PATH_GOAL were the most frequently identified image schemas.

The definition adopted here is that image schemas are not just Gestalts but conceptual structures [9]. The omission and/or addition of a SOURCE or GOAL changes the perspective of the schema [10]. It is important to differentiate whether the description explicitly states that an agent transfers an OBJECT or that an OBJECT is being transferred to a beneficiary [11]. Along the same line of argumentation, it is here claimed that the directionality of the path as well as the number of paths and objects involved in a SOURCE_PATH_GOAL schema influence the perspective of the conceptualisation. These two influential variables on the basic underlying schema as well as the four new image-schematic structures that were identified can be considered specifications of the overall MOVEMENT_ALONG_PATH schema.

Some of the terms were defined as combinations of image schemas. While only PATH-following was looked at, it could be noticed that many concepts would have been better described as combinations of a member of the PATH-following family and additional image schemas or image-schematic structures such as SCALING or CONTAINMENT, so-called image-schematic integrations [12]. Such inte-

[9] Jean M. Mandler and Cristóbal Pagán Cánovas. On defining image schemas. *Language and Cognition*, 6(4):510–532, May 2014

[10] Laura Lakusta and Barbara Landau. Starting at the end: The importance of goals in spatial language. *Cognition*, 96 (1):1–33, 2005

[11] Laura Lakusta and Barbara Landau. Starting at the end: The importance of goals in spatial language. *Cognition*, 96 (1):1–33, 2005

[12] Jean M. Mandler and Cristóbal Pagán Cánovas. On defining image schemas. *Language and Cognition*, 6(4):510–532, May 2014

grations as well as conceptual blends [13] (see Chapter 6) repeatedly surfaced in the analysis as did different forces that might be exerted to a schema. This supports the ideas in Chapter 5 in which image schemas are combined to form conceptualisations and in Chapter 7, which showed that humans often annote objects with more than one image-schematic conceptualisation.

The analysis revealed differences across the four languages which could partially be explained by grammatical decisions of the terminologists/experts, partially also by inconsistencies across languages. While the sample in this experiment is too small for any generalised conclusions, the results hint at a high consistency of image schemas occurring across languages. The exact nature of movement along a path can definitely be analysed in more detail by, for instance, investigating whether financial descriptions consider the manner of movement, e.g. as done by Papafragou et al. [2006] for a more general corpus.

Prepositions and verbs have been the most promising to yield results in bottom-up approaches (e.g. Bennett and Cialone [2014], Johanson and Papafragou [2014], Lakusta and Landau [2005]). This could not be confirmed in this experiment. Instead, synonym sets of nouns returned the most image-schematic candidates. However, this might be attributed to the selection of prepositions and verbs rather than the domain and not represent a contradiction to previous findings.

8.5 Chapter Conclusion

In this chapter, an experiment on automatic image schema extraction was presented. It relied on syntactic pattern matching following the work by Bennett and Cialone [2014] where static representations for the CONTAINMENT schema were identified in natural language. In this experiment, the purpose instead focused on empirically evaluating the PATH-following family that was introduced in Chapter 3 as well as determining if it is possible to extend it by identifying novel members of this family.

The presented method illustrates how some essential aspects of complicated terms and concepts can be described by using image schemas as a means for simplification. The analysis contributed two dimensions and four specifications to the most central SOURCE_PATH_GOAL image-schematic structure. While in this study PATH-following was the only image schema considered, in future work more image schemas could be integrated to better explain the concepts.

In terms of data sets considered, a comparison of image-schematic

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[13] Werner Kuhn. An Image-Schematic Account of Spatial Categories. In Stephan Winter, Matt Duckham, Lars Kulik, and Ben Kuipers, editors, *Spatial Information Theory*, volume 4736 of *Lecture Notes in Computer Science*, pages 152–168. Springer, 2007

structures extracted from terminologies with texts provided by financial experts could provide further insights. In addition, a comparison of the results to other domains of discourse could further strengthen the claim of a domain- and language-independent existence of image-schematic structures. This extension of the approach could also be applied to the mode of communication since gestures are frequently used to underpin linguistic descriptions of movement.

This approach not only contributes to image schema research by showing that the developmentally most relevant building blocks of our cognitive inventory are carried to abstract adult communication but also strengthens the idea that image schemas are linguistically and cognitively universal since they exist across languages. The practical use of this approach not only lies in the relation of image schemas and natural language but since the basis is provided by a formalised theory of PATH-following it also explores the relation between lexical and model-theoretical semantics as it bridge a computational linguistics research with ontology construction. In this sense, it is believed that this image-schematic method provides an interesting approach to learning spatial ontologies form multilingual text to be explored further in future experiments. Since manual ontology engineering is cumbersome and error prone, automated approaches are required.

It can be argued that the combination of linguistic and formal analysis of image-schematic structures across languages can allow for their more specialised use in automated approaches and computational systems. Thus, future work will focus on the automation of image-schematic extractions from multilingual textual evidence based on formalised theories. This also includes exploring interconnections of image schemas in form of integrations as well as conceptual blending.

This work has been extended and further developed in:

- Gromann and Hedblom [2017b],
- Gromann and Hedblom [2017a],

9
Discussion

HAL: *I'm sorry, Dave. I'm afraid I can't do that.*
Dave Bowman: *What's the problem?*

Stanley Kubrick and
Arthur C. Clarke
2001: A Space Odyssey, 1968

9.1 *Addressing the Foundation*

In the Introduction, the symbol grounding problem was introduced as one of the major problems in philosophy, linguistics and artificial intelligence. The problem asks the question how symbols acquire meaning and while it was traditionally researched in philosophy and the cognitive sciences, it has become an important problem to solve for the advancement of artificial intelligence. The presented research approaches the symbol grounding problem by focusing on not only how symbols acquire meaning, but also how the generation of meaningful concepts may take place.

Despite the contributions made here, there is still substantial efforts needed before the symbol grounding problem has a been given a satisfactory solution. Below each section will discuss in greater detail the different presented research components and how they fall into the context of the symbol grounding problem and computational concept invention. It is structured as follows: First, the research hypotheses are put under the magnifying glass to highlight any potential problems with the foundation that the research and its contributions rest upon. After this, the answers to the research questions are examined with respect to the formal approaches to image schema presented in the Chapters 3-6. Here the focus is directed towards to identify both potential weaknesses and strengths of the suggested methods and approaches that functions as the answers to the research questions. While the results of the empirical work in the final Chapters 7-8 already have been discussed in their respective chapters, a final section will place this empirical work into the framework of the dissertation and in relation to the purposes of the formal work in the previous chapters.

9.2 The Research Hypotheses Under the Looking Glass

The Introduction introduced three major research hypotheses, presented below once more, that construct the foundation for the presented research. As the results rest on the accuracy of these research hypotheses, they will be discussed in detail below.

- The theory of embodied cognition provides a stepping stone to explain cognitive phenomena involved in concept formation.
- Image schemas are conceptual building blocks learned from embodied experience. They capture spatiotemporal relationships that in combination can capture the conceptual meaning of concepts and events.
- Conceptual blending provides a sufficiently adequate theoretical framework for concept invention that could be transferred to artificial agents.

9.2.1 On the Reliability of Embodied Cognition

The first research hypothesis is the embodied mind theory which states that all cognition appears as a consequence of the body's sensorimotor experiences with the environment [1]. While this hypothesis has been found to have support (e.g. Tettamanti et al. [2005], Gallese and Lakoff [2005], Feldman and Narayanan [2004], Wilson and Gibbs [2007], Louwerse and Jeuniaux [2010]) there are counterarguments to this theory, especially to which degree the mind can be argued to be embodied [2].

Naturally, any hypothesis that has the research field somewhat conflicted in its reliability, does not provide for the most stable research foundation. However, working on the premise that for artificial systems the accuracy to model human cognition is less important than the acquired result. It can be withheld that the embodied cognition hypothesis provides a good foundation to stand on. This would mean that even if embodied cognition is only part of the truth for the underlying mechanisms of human cognition, for the artificial simulation of cognition it offers a concrete starting point.

9.2.2 On the Existence of Image Schemas

Building on the embodied mind hypothesis is the concept of image schemas. As introduced at great length in Chapter 2, image schemas are suggested to be mental generalisations learned from the sensorimotor processes [3,4,5]. Here, following tradition in the more computational domain (e.g. Kuhn [2007], St. Amant et al. [2006]), image

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[1] Lawrence Shapiro. *Embodied Cognition*. New problems of philosophy. Routledge, London and New York, 2011

[2] Lotte Meteyarda, Sara Rodriguez Cuadradob, Bahador Bahramic, and Gabriella Viglioccoa. Coming of age: a review of embodiment and the neuroscience of semantics. *Cortex*, 48: 788–804, 2012

[3] Mark Johnson. *The Body in the Mind: The Bodily Basis of Meaning, Imagination, and Reason*. University of Chicago Press, 1987

[4] Todd Oakley. Image schema. In Dirk Geeraerts and Hubert Cuyckens, editors, *The Oxford Handbook of Cognitive Linguistics*, pages 214–235. Oxford University Press, Oxford, 2010

[5] Jean M. Mandler. *The Foundations of Mind: Origins of Conceptual Thought: Origins of Conceptual Though*. Oxford University Press, New York, 2004

schemas are defined as spatiotemporal relationships. While the image schemas are multimodal and exist on a more fluid and abstract level than what has been presented in the computational domains, this definition is most likely a great simplification. However, as spatiotemporal relationships and image-schematic transformations are complicated enough to formalise, this restriction is motivated as it allows for a more feasible research program. It is recommended that future work devotes itself to approaching image schemas from a more 'sensory-complete' direction.

As the foundation builds on the embodied cognition hypothesis, there is no practical reason to question the existence of image schemas. However, there are numerous problems with image schemas research. For instance, while cognitive linguistics has been increasingly interested in researching spatial language since the work by Talmy [1983], it is not clear how image schemas mentally manifest. While spatial language is a clear indicator of the existence of spatially related conceptual building blocks, the relationship between language and image schemas is less obvious. For instance, it is clear that language is heavily context-dependent and learned from the present culture, as seen, for instance, in differences of the levels of specificity of CONTAINMENT in English and Korean [6].

In order to gain further support for this from a more pre-linguistic direction, developmental psychology demonstrates how infants gain conceptual knowledge that (to as a large degree as such studies can indicate) correspond to the spatiotemporal relationships defined by the image schemas [7].

Back-tracing from these research findings, it is plausible that the human mind constructs a mental representation for the image-schematic concepts, but it remains a mystery if this is directly linked to the neural activation of the sensorimotor cortices or if this is a rewritten representation in terms of a more classic view of cognition. This question remains for neuroscience and further research to answer.

Whether image schemas exist as mental representations or direct activation in the sensorimotor cortex [8] is at this point deemed irrelevant for the integration of image schemas into artificial intelligence research.

9.2.3 On the Accuracy of Conceptual Blending as a Model for Concept Invention

Regarding the cognitive framework that underlay concept invention, analogy has been suggested to be a common and efficient method to transfer information from one domain to another [9]. As conceptual

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[6] Laraine McDonough, Soonja Choi, and Jean M Mandler. Understanding spatial relations: Flexible infants, lexical adults. *Cognitive Psychology*, 46(3):229–259, 5 2003

[7] Jean M. Mandler. *The Foundations of Mind: Origins of Conceptual Thought: Origins of Conceptual Though*. Oxford University Press, New York, 2004

[8] Lawrence Shapiro. *Embodied Cognition*. New problems of philosophy. Routledge, London and New York, 2011

[9] Douglas Hofstadter. *Fluid Concepts and Creative Analogies*. Basic Books, 1995

blending relies on the same underlying mechanisms, there are no direct reasons to question the theory's practical benefits [10]. Additionally, conceptual blending has, in its own right, been deemed to be cognitively plausible [11,12,13] and computationally applicable [14].

As was discussed in Chapter 1, creativity comes as a multifaceted phenomenon where not only cognitive but bodily skills are important [15,16]. Additionally, the role of pre-existing knowledge and long-term memory has been a topic of debate [17]. Therefore, it is most likely more to the story of creativity and concept invention than exclusively conceptual blending. As with most cognitive mechanisms, concept invention does not allow for straightforward investigations. Arguably one can only speculate that blending is one of many possible methods human cognition utilise when inventing concepts. However, as reasoned with the previous hypotheses, for computational research on concept invention conceptual blending provide a useful framework (e.g. Goguen and Harrell [2010], Hois et al. [2010], Kutz et al. [2012, 2014b]).

9.3 *Questioning the Answers*

In the Introduction three questions that the research aimed to answer were introduced. The questions were the following:

- First, as image schemas are abstract concepts without defined borders: *How can they be defined and organised?*
- Second, as image schemas are fluid mental patterns: *Is it possible to use the concrete methods in formal knowledge representation to formally capture the image schemas?*
- Third, as image schemas play a role in analogical reasoning and causal predictions: *Is it possible to use image schemas to aid computational concept invention? If so, how?*

Below each of these research endeavours and their results will be addressed in their respective sections.

9.3.1 *Structuring Image Schemas*

One main focus of the present research was to address how image schemas can be integrated into a formal framework for artificial intelligence in order to solve the symbol grounding problem. However, as was demonstrated in Chapter 2 there are several problems with the state of the art in image schema research. The first problem follows from the interdisciplinary research field, meaning that there is disagreement on terminology on what image schemas are as well as

[10] Mark Turner. *The Origin of Ideas: Blending, Creativity, and the Human Spark*. Oxford University Press, 2014; and Gilles Fauconnier. *Mappings in Thought and Language*. Cambridge University Press, Cambridge, 1997

[11] Raymond W. Gibbs. Making good psychology out of blending theory. *Cognitive Linguistics*, 11(3–4):347–358, 2000

[12] Fan-Pei Gloria Yang, Kailyn Bradley, Madiha Huq, Dai-Lin Wu, and Daniel C Krawczyk. Contextual effects on conceptual blending in metaphors: An event-related potential study. *Journal of Neurolinguistics*, 26(2):312–326, 2013

[13] Joseph E. Grady. Cognitive mechanisms of conceptual integration. *Cognitive Linguistics*, 11(3-4):335–345, 2001

[14] Marco Schorlemmer, Roberto Confalonieri, and Enric Plaza. The Yoneda Path to the Buddhist Monk Blend. In *Proceedings of the 2nd Joint Ontology Workshops (JOWO)*, 2016

[15] Mark A. Runco and Ivonne Chand. Cognition and creativity. *Educational Psychology review*, 7(3):243–267, 1995

[16] Arne Dietrich. The cognitive neuroscience of creativity. *Psychonomic bulletin & review*, 11(6):1011–26, 12 2004

[17] Rex E. Jung, Charles Gasparovic, Robert S. Chavez, Ranee Flores, Shirley M. Smith, Arvind Caprihan, and Ronald Yeo. Biochemical support for the "threshold" theory of creativity: a magnetic resonance spectroscopy study. *The Journal of neuroscience*, 29(16): 19–25, 2009

that their abstract nature makes them difficult to properly identify. By following the convention in the more computational research (e.g. Kuhn [2002]) and exclusively treating image schemas as spatiotemporal relationships some of these problems could be avoided as image schemas could be approached mathematically as object relations in Euclidean space with a fourth temporal dimension in the form of linear temporal logic. This way the results are in accordance with existing work in geographical information science and qualitative spatial reasoning.

Second, due to the abstract nature of image schemas, they are difficult to identify and categorise already from a cognitive point of view. This problem manifests in there existing no comprehensive and agreed upon list of image schemas, despite some attempts [18]. Even with a restriction to the image schemas that are purely spatiotemporal, the instances are undefined, vague and overlapping. Additionally, they appear as both simple and complex construction [19], where the general consensus is that complex image schemas result from combining elements taken from various, more simple, image schemas [20]. In Chapter 2 these problems were summaries under the structure problem and the categorisation problem.

The structure problem captures the complexity to determine when a spatiotemporal phenomenon is 'image-schematic'. Previous literature on image schemas suggests a structured hierarchy of image-schematic components where simpler primitives can be combined into image schemas (e.g. Mandler and Cánovas [2014]). However, this in itself does not provide a clear-cut definition of the criterion of image schemas. Instead, it provides a more flexible definition in terms of specificity and complexity, allowing for a broader interpretation of image-schematic structures. Likewise, the introduced categorisation problem captures that even if the concept is image-schematic it is not always so straightforward to determine to which image schema it belongs. Many mentioned structures in the image schemas research (e.g. IN, OUT, BLOCKAGE) are difficult to isolate as only one spatiotemporal relationship as they appear as combinations of simpler image schemas.

These two problems were addressed primarily in the 3rd Chapter where image schemas are suggested to be clustered into hierarchical families. It follows the sketched ideas of Johnson [1987] where similar image schemas are grouped into larger groups such as the 'spatial motion group' and the 'force group'. While inspired by this categorisation, the suggestion does not group together 'different' image schemas, but aims to break apart the individual image schemas. This method is inspired by the findings in developmental psychology and the image schema hierarchy introduced by Mandler and Cánovas

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[18] Mark Johnson. *The Body in the Mind: The Bodily Basis of Meaning, Imagination, and Reason*. University of Chicago Press, 1987

[19] Ming-yu Tseng. Exploring image schemas as a critical concept : Toward a critical-cognitive linguistic account of image-schematic interactions. *Journal of literary semantics*, 36:135–157, 2007

[20] Todd Oakley. Image schema. In Dirk Geeraerts and Hubert Cuyckens, editors, *The Oxford Handbook of Cognitive Linguistics*, pages 214–235. Oxford University Press, Oxford, 2010

[2014].

The core point of how to structure image schemas is derived from developmental psychology and linguistics which demonstrate how image schemas are fine-tuned in cognitive development [21] as well as existing in natural language (and, as spatiotemporal relationships, in the real world) in many different forms [22].

Building from these ideas, a family of image schema members can be built that begins at the most general form of a particular image schema and by the addition of spatial or conceptual primitives (such as those introduced by Mandler and Cánovas [2014], Lakoff and Núñez [2000], Wierzbicka [1996]), the graph branches out with increasingly complex family members. In Chapter 3, two such families were introduced, the Two-Object family and the PATH family (see Figure 9.1 for a reminder of the Two-Object family and Figure 9.2 for a reminder of the PATH family.).

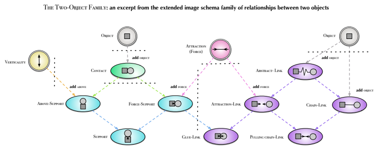

Figure 9.1: The Two-Object family revisited. See Figure 3.1 on Page 73.

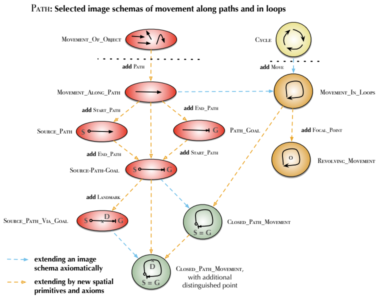

Figure 9.2: The PATH family revisited. See Figure 3.3 on Page 80.

By structuring image schemas into families two issues are bypassed. The first is that it is no longer a problem if it is unclear when an image schema is 'complex' enough to have become more than a spatial primitive. Analogous, the second benefit is that it does not matter if the borders between different image schemas overlap since spatial and conceptual primitives can be 'borrowed' between families. This means that the family structure does not only address the structure problem but also provides a feasible solution to the categorisation problem. As one image schema naturally becomes a network ranging from a simple generalisation to increasingly complex construction by the addition of spatial primitives, it is possible to 'cross-breed' and inherit spatial primitives from other image schema families. For instance, the SUPPORT schema inherits a sense of 'force' from an image schema in the force group (in Chapter 3 this was represented using ATTRACTION) and MOVEMENT_IN_LOOPS can be described as a CYCLE that has inherited movement from the PATH family. Another benefit of allowing this cross-breeding of image schematic families is that by combining elements, increasingly complex structures can be described using image schemas. In Chapter 5 combinations of image schemas were discussed at great lengths. Here different kinds of image-schematic combinations could result in more complex image-schematic structures (such as IN, OUT and CAUSED_-MOVEMENT) as well as model simple events and image schema profiles [23] (formally approached by e.g. St. Amant et al. [2006]).

This way of structuring image schemas does not only hold appeal from a linguistic and psychological direction but allows for a rather straightforward method to formally structure image schemas. For any formal representation, it is simply possible to extend the image schema family by additional axioms, as demonstrated in Chapter 3

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[21] Tim Rohrer. Image schemata in the brain. In Beate Hampe and Joseph E Grady, editors, *From perception to meaning: Image schemas in cognitive linguistics*, volume 29 of *Cognitive Linguistics Research*, pages 165–196. Walter de Gruyter, 2005

[22] Brandon Bennett and Claudia Cialone. Corpus Guided Sense Cluster Analysis: a methodology for ontology development (with examples from the spatial domain). In Pawel Garbacz and Oliver Kutz, editors, *8th International Conference on Formal Ontology in Information Systems (FOIS)*, volume 267 of *Frontiers in Artificial Intelligence and Applications*, pages 213–226. IOS Press, 2014

[23] Todd Oakley. Image schema. In Dirk Geeraerts and Hubert Cuyckens, editors, *The Oxford Handbook of Cognitive Linguistics*, pages 214–235. Oxford University Press, Oxford, 2010

and Chapter 4.

One issue that still remains a problem, regardless of the structuring method, is the problem of 'completeness'. How is it possible to determine when an image schema family has all the members represented? In many ways, this is a not a major concern for artificial intelligence as there is no particular reason why all members of a family need to be represented. Additionally, it is uncertain as to whether all potential members from a logical perspective exists on a cognitive level. This problem was illuminated in the experiment presented in Chapter 8, where empirically support was found for the PATH family but also support to include members that had not previously been considered was found. While this extension provided a better representation of a PATH-family, it does not affect the usefulness of the initial PATH-following family in Chapter 3.

9.3.2 *Using Logic to Model Embodied Cognition and the* ISL^{FOL}

The second research question[24] asked if it is possible to take something as abstract as the generalisation that defines the image schemas and turn them into computational representations useful for computational systems.

In order to frame this question in the light of embodied cognition, let us return to how Mandler [2009] argued for there to be two sets of processes involved in concept learning; perceptual and conceptual. The first set of processes focuses on the categorisation of sensory-stimuli and the second set is responsible for making sense of the experienced perception.

While it remains uncertain how either of these sets of processes manifests as cognitive phenomena, the literature on embodied cognition suggests that it is repeated exposure to sensorimotor experiences that form mental generalisations, such as image schemas, that are used to ground concepts and their symbols [25,26].

Embodied cognition has a stronghold in the statistical computational methods that simulate Hebbian learning as it is a plausible model for the nervous system, and a substantial body of work (e.g. Nayak and Mukerjee [2012b], Rosman and Ramamoorthy [2011], Aguilar and Pérez y Pérez [2015]) exists on approaching image-schematic information from this direction. However, machine learning techniques do not provide a solution for all the problems at hand. In Chapter 1, two psychological theories involved in the perceptual processes were presented. These were the recognition-by-components theory which suggests that object identification is done through the breakdown of visual objects into simple geometric shapes called geons, and prototype theory which argues that all concepts have a

[24] Second, as image schemas are fluid mental patterns: *Is it possible to formally represent the individual image schemas?*

[25] Lawrence Shapiro. *Embodied Cognition*. New problems of philosophy. Routledge, London and New York, 2011

[26] George Lakoff and Mark Johnson. *Philosophy in the Flesh*. Basic Books, 1999

prototypical exemplary to which all instances are more or less similar. These kinds of perceptual classification techniques are very suitable to be approached through different forms of machine learning. However, for the conceptual processes, it is not quite as straightforward. The conceptual processes were in Chapter 1 isolated to image schemas and the related, affordances. While image schemas can be argued to be a form of abstract, 'conceptual geons', they are not, as of yet, that easily identified through machine learning. Chapter 8, and the two follow-up studies (Gromann and Hedblom [2017a,b]) that both were devoted to extracting image schemas from natural language through machine learning, demonstrated that identifying image schemas in the 'real world' is a non-trivial task. In Chapter 2, this was presented as 'the structure problem', namely, that it is not clear how image schemas can be identified as even one particular image-schematic concept appear in multiple forms, on several complexity levels and that they, in natural language, are neither directly tied to the prepositions, nor to action verbs, but rather appear to be embedded into the context of sentences.

With this in mind, the present research program completely bypassed the perceptual processes and instead demonstrated how image schemas, that can be identified in natural language and research on developmental psychology, can be directly modelled through classic knowledge representation. This way, a representation of image schemas would not only allow for the different levels of specificity through the structure of family hierarchies but would also ensure that the representation has full enclosure of all desired semantic content.

Naturally, the perceptual processes are of equal importance as the conceptual processes in order to create a fully autonomous agent and it is recommended that the findings of this research are combined with sub-symbolic methods to in more completion capture the processes of concept learning (see Besold et al. [2017a] for an overview).

ISL^{FOL}

In Chapter 4 the Image Schema Logic, ISL^{FOL}, a logical language for the spatiotemporal relationships that characterise image schemas, was introduced. The language is inspired by previous formalisations of image schemas (e.g. Bennett and Cialone [2014], Galton [2010], Frank and Raubal [1999]) that instead of modelling image schemas entirely with first-order logic (FOL) use spatial calculi. The benefit of using spatial calculi is that semantically these languages already contain spatial information, essential for the image schemas. Moreover, qualitative spatial logics have been designed to capture more adequately the way humans conceptualise and reason about space [27]. As the basic idea with image schemas is that they are a conceptual skeleton for other information [28,29,30], the ISL^{FOL} provides a perfect initial representation to capture the image-schematic concepts. However, as with any initial methods, there are issues that need to be addressed.

The first problem concerns movement when only one object is present. Building on the Qualitative Trajectory Calculus (QTC) [31], in particular, its variant QTC_{B1D}, only one-dimensional movements *between* objects are concerned. This means that using only QTC it is not possible to describe absolute movement. When representing the PATH-following family, where only one OBJECT is involved, this becomes a significant problem. However, ISL^{FOL} does not only take OBJECT into account in its semantics, also regions and paths are possible to define. This means that absolute movement of an object can be defined as 'it exists a region to which the object moves'. From a more cognitive perspective, an additional point of reference was given, *Me*. This is the point in which a perceiver is observing an image schema event. For the current uses of ISL^{FOL}, *Me* has not been given a concrete function. However, the concept has great importance for the future extension of ISL^{FOL} where image-schematic transformations such as SCALE, which is involved in the perception of movement coming closer and going further away, and SELF_MOVEMENT, the image schema that denotes the initiation of movement without any external force. Additionally, by centring an image-schematic event around a perceiver, *Me*, scenarios in which the perceiver is moving/-transforming together with the object in question can be taken into account. For instance, a person sitting inside a car would not perceive the car as moving, but would rather argue that the 'landscape is flying by'.

A second problem concerns the relationship between objects. QTC presupposes 'moving point objects' whereas the spatial dimension represented using RCC [32] presuppose regions. As image schemas demonstrate how objects can be in CONTACT, go INto other objects etc., it is important to address how to calculate the centre of an object. As was argued in Chapter 4, this can and must be done in different ways. For an image schema such as CONTACT, it is enough to calculate the minimal distance between two objects. As an object is still in contact even with the most minimal level of 'touch' (in RRC-8 the relationships: EC or ¬DC). Picture a ball rolling off a table, it is not until the ball has fallen off the table that there is no longer any contact between the two objects. In comparison, for the dynamic aspects of CONTAINMENT, the distance cannot be calculated based on the minimal distance, as it must be possible for objects to occupy the same region (in RRC-8 the relationships: PO, TPP and NTPP). Here the dis-

[27] Anthony G. Cohn and Jochen Renz. Qualitative spatial representation and reasoning. In F. van Harmelen et al., editor, *Handbook of Knowledge Representation*, pages 551–596. Elsevier, Oxford, 2007

[28] Zoltán Kövecses. *Metaphor: A Practical Introduction*. Oxford University Press, Oxford, USA, 2010

[29] Barbara Dancygier and Lieven Vandelanotte. Image-schematic scaffolding in textual and visual artefacts. *Journal of Pragmatics*, 2017. In Press

[30] Tony Veale and Mark T. Keane. Conceptual Scaffolding: a Spatially Founded Meaning Representation for Metaphor Comprehension. *Computational Intelligence*, 8(3):494–519, 1992

[31] Nico Van De Weghe, Anthony G. Cohn, Guy De Tré, and Philippe De Maeyer. A qualitative trajectory calculus as a basis for representing moving objects in geographical information systems. *Control and cybernetics*, 35(1): 97–119, 2006

[32] David A. Randell, Zhan Cui, and Anthony G. Cohn. A spatial logic based on regions and connection. In *Proceedings of the 3rd International Conference on knowledge representation and reasoning*, 1992

tance needs to be calculated based on the geometric centre or when VERTICALITY is involved even this will not suffice. Visualise the event in which the ball is instead thrown into a basket. Here the minimal distance is matched to the maximal distance of the basket. In its current version, ISL^{FOL} only calculate the distance between objects based on their geometric centre of the occupied region. However, dependent on the level of detail of the shape of the object has in the model, this can become a problem. For instance, if one 'takes the jelly out of the doughnut', the geometric centre does not change much. Likewise, with the current state of the model, it is possible to sail into Florida, while actually never embarking as the geometric centre of the occupied region lies in the Gulf of Mexico. Naturally, the state of ISL^{FOL} and the current formalisations are based on a much more abstract level in which the exact spatial details of the logic hold little importance. However, if ISL^{FOL} is used to model real-life scenarios rather than abstract conceptualisations, these restrictions need to be addressed. This would also include restrictions on the size of the regions and the objects as, at least physically, a larger object cannot be contained within a smaller object [33].

Another challenge for ISL^{FOL} is the temporal dimension. Time is difficult to conceptualise as well as to capture formally and often the temporal dimension is simply conceptually mapped onto a spatial dimension [34,35]. In ISL^{FOL}, linear temporal logic (LTL) is used to describe the sequence of states. In Chapter 4 and more prominently in Chapter 5, the simplicity of using sequential steps were put to the test with success to describe scenarios such as BLOCKAGE, CAUSED_MOVEMENT and BOUNCING. These kinds of image schema combinations were in Chapter 5 referred to as 'sequential'. Naturally, LTL presupposes a one-dimensional timeline and is, therefore, perfectly suited for such scenarios. For increasingly complex scenarios in which time is branching or non-linear, the current temporal representation in ISL^{FOL} needs to be revised. Here, inspiration can be found in the large variety of temporal logics that have been proposed to model various temporal aspects of natural language [36,37]. However, for the time being, the current state of ISL^{FOL} provides a satisfactory solution to this problem.

9.3.3 *Formal Integration of Image Schemas into Conceptual Blending*

The third research question[38] concerned the integration of formalised image schemas into a computational framework for concept invention. One of the main hypothesis was that conceptual blending provides a good starting point for how concept invention takes place in human cognition. Currently, there exist several attempts to formalise

[33] Antony Galton. The Formalities of Affordance. In Mehul Bhatt, Hans Guesgen, and Shyamanta Hazarika, editors, *Proceedings of the workshop Spatio-Temporal Dynamics*, pages 1–6, 2010

[34] Lera Boroditsky. Metaphoric structuring: Understanding time through spatial metaphors. *Cognition*, 75(1):1–28, 2000

[35] Michiel Van Lambalgen and Fritz Hamm. *The Proper Treatment of Events*. Explorations in Semantics. Wiley, 2005

[36] Arthur N. Prior. *Past, Present and Future*. Oxford University Press, Oxford, 1967

[37] Johan Van Benthem. *The Logic of Time: A Model-Theoretic Investigation into the Varieties of Temporal Ontology and Temporal Discourse*. D. Reidel Publishing Company, Dordrecht, Holland, 1983

[38] Third, as image schemas play a role in analogical reasoning and causal predictions: *Is it possible to use image schemas to aid computational concept invention? If so, how?*

conceptual blending (e.g. Goguen and Harrell [2010]) but the major problem of how to consistently produce blends that are not only novel but also meaningful remains a problem [39] [40]. As current blending systems do not possess any understanding of which blends are conceptually meaningful and which are not, the number of blends will grow exponentially. In Chapter 6 this was approached by suggesting that the conceptual spaces to be blended should be blended on the basis of image schemas. As image schemas are inherently meaningful the information they possess can be transferred into the blend.

The chapter demonstrated how image schemas can be integrated into a range of different methods, first by being given higher priority when transferred into the blend, second to be used as the generic space.

To successfully investigate and evaluate the fruitfulness of this idea, a more comprehensive formalisation of image schemas is needed than the formalisations presented here. This initiated repository only allows for minor investigations and if computational blending is to be taken to its full potential, a whole range of image schematic families and their interconnections needs to be made available to a blending system.

In addition to the extension of the image schema repository, the blending system needs to be given substantial information on the input spaces. The examples in Chapter 6 are hand-crafted to demonstrate a general idea, in which multiple blends can take place that are neither novel nor useful. The image schemas are only one of many potential semantic components that are needed to increase the success automatic system have for performing conceptual blending and analogical reasoning. Additional components that could push concept invention further would be to include mapping rules. Here, it would be possible to expand the ISL^{FOL} language to include properties and other characteristics and map their semantic content in a purely syntactic fashion. However, this remains as future work.

9.4 Empirical Starting Points

In addition to the theoretical work, the dissertation provides two empirical studies presented in Chapter 7 and Chapter 8, that intend to strengthen some of the presented ideas. The methods and the results of these studies were at length discussed in their respective chapter so this will not be repeated. Here the results are only discussed in how they relate to the rest of the results.

[39] Mark A. Runco and Garrett J. Jaeger. The standard definition of creativity. *Creativity Research Journal*, 24(1):92–96, 2012

[40] Margaret A. Boden. Computer models of creativity. *AI Magazine*, Fall 2009

9.4.1 *Image Schemas as Building Blocks*

One of the main assumptions in the dissertation is that there exists a distinct connection between image schemas and objects, events and scenarios that can be summarised as a conceptual skeleton for the underlying meaning of these concepts.

The dissertation looked at this in primarily two chapters, Chapter 5 and Chapter 7. The first looked at how combinations of image schemas could formally be deemed to model simple events such as BOUNCING. Here several different methods of how to combine image schemas were discussed. In the second mentioned chapter, image schemas were empirically investigated in how they directly are connected to a set of common objects. While the experimental design needs tweaking for future replicas of the study (see Section 7.4.1 for more details) the results do provide support for the hypothesis.

As mentioned, the third research question focused on how image schemas could be used in computational concept invention through the integration into conceptual blending. As there currently exists no method to automatically assign image schemas, formal or informal, to neither objects nor events it is currently not possible to proceed with an automatic blending system. First, the conceptual spaces that define certain objects need to be assigned appropriate image schemas. In this dissertation, the possibility to do this in the first place was investigated. The results show that while there is some divergence in a number of image schemas assigned, in particular in more conceptual complex objects (e.g. camera, banana), it is possible to core down objects into image schemas. It should be possible to extend these findings to not only concrete objects but abstract concepts and events as well. The work in Chapter 5 demonstrated that it is possible to describe the underlying 'skeletal' structure of events with sequences of combinations.

Naturally, for the conceptual space of any object, concept and event there will be additional information that the spatiotemporal relationships present in the image schemas, cannot capture. These are the characteristics and the 'flesh' of metaphors and concepts. However, as discussed above, this could be addressed by extending the ISL^{FOL} or adding a distinct concept language that would work in parallel to the included FOL.

9.4.2 *Automatic image schema extraction*

The final chapter of the dissertation (Chapter 8) presents the first steps towards an automatic method to extract image schemas from natural language. This is the first of a series of experiments [41] [42] [43] that aim to develop an automatic method for this purpose.

[41] Dagmar Gromann and Maria M. Hedblom. Breaking Down Finance: A method for concept simplification by identifying movement structures from the image schema Path-following. In *Proceedings of the 2nd Joint Ontology Workshops (JOWO)*, volume 1660, Annecy, France, 2016. CEUR-WS online proceedings

[42] Dagmar Gromann and Maria M. Hedblom. Kinesthetic mind reader: A method to identify image schemas in natural language. In *Advances in Cognitive Systems*, volume 5, pages 1–14, 2017a

[43] Dagmar Gromann and Maria M. Hedblom. Body-Mind-Language: Multilingual Knowledge Extraction Based on Embodied Cognition. In *Proceedings of the 5nd International Workshop on Artificial Intelligence and Cognition (AIC-2017)*, Larnaca, Cyprus, November 2017b

This research endeavour is important for two different reasons. In Chapter 2 it was argued that there currently exists no comprehensive or agreed upon list of image schemas. It follows that the first purpose of such a method is to further extend the image schema repository, argued to be a crucial component before the computational blending such as the work demonstrated in Chapter 6, could be possible. The work presented in this chapter looked in isolation at the PATH family and could not only provide empirical support but also identify new members of the family.

The second purpose is not with the purpose of extracting the image schemas and their concepts for a secondary purpose but to directly use them in that context of the natural language. While the dissertation does not discuss to great depth the problems of natural language understanding and generation other than in the more creative aspects, the image schemas and their equivalence in linguistic expressions could help to create systems that better 'reply' and react to certain concepts, including also more abstract scenarios and metaphors. Before any conclusions on the impact of these ideas, further research is needed to evaluate their prospects in artificial intelligence systems.

Conclusion and Future Work

Contributions and Conclusions

The presented research deals with the intersection of human and computational concept invention based on the problem of symbol grounding. By looking at the existence of image schemas, conceptual building blocks that naturally occur in language and analogical reasoning, the presented work offers a step forward in the computational approaches to symbol grounding and computational concept invention. Within this research program, three major questions were asked that focus on the intersection between the cognitive existence of image schemas, their formal actualisation and their usefulness in computational concept understanding and invention.

The first contribution stemmed from the first research question which deals with how the undefined and abstract nature of the cognitive patterns that are the image schemas could be formally structured (see Chapter 3). By following the state of the art in the cognitive sciences, research from linguistics and developmental psychology provided a foundation for how to formally structure the image schemas. Previous research illuminates that image schemas can be argued to exist in multiple versions on different levels of specificity. Therefore, the formal approach was to sort the image schemas into clusters of similar conceptual structures, generating families of particular image schemas. As a demonstration, a Two-Object family encompassing the image schemas CONTACT, SUPPORT and LINK, and a PATH-following family encompassing dynamic movement, as different forms branching out from the SOURCE_PATH_GOAL image schema, were introduced. The family structure was further specialised by presenting them as theory graphs where the most general forms are axiomatically extended by the addition of conceptual and spatial primitives as introduced by research in developmental psychology [44].

The second contribution concerns the formal translation of the members of the image schema families (see Chapter 4). For this purpose, ISL^{FOL}, the image schema logic, was introduced as a formal

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[44] Jean M. Mandler and Cristóbal Pagán Cánovas. On defining image schemas. *Language and Cognition*, 6(4):510–532, May 2014

language building from previous research in geographical information science, qualitative spatial reasoning and the previous formalisations of image schemas and similar notions such as affordances that have been conducted (e.g. Bennett and Cialone [2014], Galton [2010]). The formal language is built from the Regional Connection Calculus (RCC) [45] to represent the spatial region occupied by objects, the Qualitative Trajectory Calculus (QTC) [46] to account for relative movement between objects (or the perceiver) and Linear Temporal Logic (LTL) to describe sequential events for the more dynamic image schemas. In conclusion, ISL^{FOL} provides a powerful tool to represent individual members of the image schemas but also how to represent image-schematic events and conceptualisations as those present in image schema profiles [47] (see Chapter 5).

The third contribution is directly connected to how the structured and formalised image schemas can play a role in computational concept invention and computational creativity as a whole (see Chapter 6). The third research question was approached by integrating image schemas into conceptual blending, a theoretical framework for concept invention based on the mechanisms of analogical thinking [48]. Within this research program, it was suggested that image schemas can play several roles. First, in their role as conceptual building blocks, they are inherently meaningful and it can, therefore, be claimed that they should to a larger degree be inherited to the blends. Second, as image schemas are often the conceptual skeleton in analogies, they could compose the conceptual skeleton for the blending procedure as well. Additionally, by structuring image schemas as hierarchical families where each image-schematic concepts becomes increasingly specialised, it is possible to identify members of the same image schema in different input spaces, regardless of them being representations on different levels in a particular family hierarchy.

These three research questions were accompanied by two related empirical studies. The first provides empirical support to one of the fundamental hypotheses of the dissertation, namely that image schemas play a role during conceptualisations of objects, and arguable could be extended to events (see Chapter 7). The second experiment introduces a first step to an automatic method to identify and categorize image schemas in natural language. It provides empirical support to structuring image schemas in hierarchical families, as introduced in Chapter 3. It is a still-missing fundamental step before the presented research can be used on a larger scale for the advancement of artificial intelligence and natural language understanding research (see Chapter 8).

These research results provide support for the ideas that image

[45] David A. Randell, Zhan Cui, and Anthony G. Cohn. A spatial logic based on regions and connection. In *Proceedings of the 3rd International Conference on knowledge representation and reasoning*, 1992

[46] Nico Van De Weghe, Anthony G. Cohn, Guy De Tré, and Philippe De Maeyer. A qualitative trajectory calculus as a basis for representing moving objects in geographical information systems. *Control and cybernetics*, 35(1): 97–119, 2006

[47] Todd Oakley. Image schema. In Dirk Geeraerts and Hubert Cuyckens, editors, *The Oxford Handbook of Cognitive Linguistics*, pages 214–235. Oxford University Press, Oxford, 2010

[48] Gilles Fauconnier and Mark Turner. Conceptual integration networks. *Cognitive Science*, 22(2):133—187, 1998

schemas are not to be limited to a cognitive research area alone, but that image schemas have great potential to be integrated into artificial intelligence research as an aid in concept formation, natural language understanding and commonsense reasoning problems, all research areas that still need computational attention.

Research Influence and Importance

These novel research findings show promise of a successful integration of the cognitive phenomenon of image schemas as a bridge to solve some of the areas in which artificial intelligence struggles with.

The presented research program primarily looked at creativity through concept formation, but the ideas are not exclusive to the domain of computational creativity. The cognitively inspired building blocks provide a potential ground to work with semantics rather than with syntax while simultaneously remain in the classic area of knowledge representation. This means that the methods introduced in this dissertation are compatible with a range of existing applications, systems and formal frameworks (e.g. HDTP [49], Hets [50]). For instance, formalised image schemas can help analogical reasoning tools to make better inferences that closer resembles the meaning transfer made by humans. This means that by providing an artificial agent with the information that a cup affords CONTAINMENT, it can analogically transfer this information to similar situations with objects of similar features, the system can perform analogical reasoning and make predictions.

Another research area that could benefit from the work presented on the formal representation of image schemas is research on commonsense modelling and reasoning. As research on commonsense modelling struggles to represent even fairly simple scenarios (e.g. Morgenstern [2001], Steedman [2002]), the spatiotemporal information found in image schemas could function as a sort of formal building blocks that in their entirety could be attached to concepts and different scenarios. This way, the embedded spatiotemporal information, and the associated affordances [51], can be reused in a wide variety of scenarios without being reformulated. This is not only cognitively plausible but also provide scientists with a possibility to speed up and bypass large parts of the axiomatisation process.

While analogical reasoning and commonsense modelling is part of a more theoretical area of computational research, computationally approached image schemas can also be applied in a more concrete research area. The dissertation repeatedly demonstrated how image schemas can be found in natural language, both in concrete and more abstract domains. As artificial agents arguably can be called

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[49] Martin Schmidt, Ulf Krumnack, Helmar Gust, and Kai-Uwe Kühnberger. Heuristic-Driven Theory Projection: An Overview. In H. Prade and G. Richard, editors, *Computational Approaches to Analogical Reasoning: Current Trends*, volume 548 of *Computational Intelligence*. Springer, 2014b

[50] Till Mossakowski, Christian Maeder, and Klaus Lüttich. The Heterogeneous Tool Set. In Orna Grumberg and Michael Huth, editors, *TACAS 2007*, volume 4424 of *Lecture Notes in Computer Science*, pages 519–522. Springer, 2007

[51] James J. Gibson. The theory of affordances. In Robert Shaw and John Bransford, editors, *Perceiving, Acting, and Knowing: Toward an Ecological Psychology*, pages 67–82. NJ: Lawrence Erlbaum, Hillsdale, 1977

'ignorant' to the actual meaning of words, in comparison to how humans may be argued to be aware, the image schemas can also be used as a grounding tool for systems dealing with natural language understanding. By annotating objects with associated image schemas (see Chapter 7), events and scenarios with combinations of image schemas following the notion of image schema profiles (see Chapter 5), systems may use this information to better 'understand' natural language, make better metaphorical translations and perhaps also display what could be described as a deeper understanding of abstract language.

In summary, the conducted research outline the possibilities of integrating image schemas into artificial intelligence research. Artificial intelligence is still struggling to simulate the areas of human cognition that differs from what traditionally would be called intelligent, and instead, are embedded in a domain more accurate to be called a 'soul'. The presented research has demonstrated how image schemas could be of assistance in grounding some of the symbols involved in natural language understanding, analogical and commonsense reasoning as well as providing the first step into the increasingly difficult area of computational concept creativity. Substantial as the ideas and research conducted are, this research program has only been initiated and as with any good research it leaves more questions than it provided answers, hence, further research is required. In the next section, a few directions on where to take this research further are presented.

Future work

The presented research leaves as many questions as it provides answers. In order to fully evaluate the impact of the research results and ideas, further research is needed. Below is an outline of four research areas that should follow from this work.

1. The relationship between image schemas and concepts and events
2. Expand the image schema repository
3. Formal evaluation of image schemas in computational conceptual blending
4. Automatic identification of image schemas in natural language

1. The Relationship Between Image Schemas and Concepts and Events

From a more cognitive perspective, the real-life role of image schemas needs further empirical support. In Chapter 7, the connection between image schemas and a series of everyday objects was investigated. The results showed an interesting connection between image schemas, in particular in respect to the affordances they contain, and the corresponding objects. However, this research area has only been initiated and in order to properly determine the role image schemas play in object conceptualisations, further experiments needs to be set-up. This is also true for the combinations of image schemas that were suggested to represent events, following the work outlined in Chapter 5. Potential research methods would be to use Crowdsourcing to quickly get access to a large number of participants that can map image schemas to objects and events. One major obstacle to overcome is how to provide the participants with an intuitive and descriptive representation of the image schemas without being too obvious. In Chapter 7, a series of image schema illustrations were used with mixed results. For future studies, a better representation to properly access the ideas behind the image schemas is required, for instance, small video clips that can also include the temporal dimension and the involved image schema transformations.

2. *Expand the Image Schema Repository*

From a computational point of view, one of the most immediate research goals to follow from the presented work is to provide a more substantial repository of image schemas, their family memberships as well as their full formalisations. This can be done either through literature reviews in which all the mentioned image schemas are sorted into appropriate categories and from there dissected into the right level of the hierarchy or through empirical methods such as conceptualisation experiments with infants or linguistics extraction methods as, for instance, that initiated by Bennett and Cialone [2014] and the one presented in Chapter 8 [52,53].

3. *Formal Evaluation of Image Schemas in Computational Conceptual Blending*

One of the major contributions of this dissertation is how image schemas can be used in analogy engines and computational conceptual blending tools. Theoretically, these ideas have a high impact factor, but this needs proper empirical validation. For this, the expanded repository of formalised image schemas can be combined with the image schema annotated objects/events to automatically generate conceptual spaces and formalised ontologies. For instance, if a 'coffee cup' and a 'house' have empirically been annotated with CONTAINMENT and this has been given a formal representation in

[52] Dagmar Gromann and Maria M. Hedblom. Breaking Down Finance: A method for concept simplification by identifying movement structures from the image schema Path-following. In *Proceedings of the 2nd Joint Ontology Workshops (JOWO)*, volume 1660, Annecy, France, 2016. CEUR-WS online proceedings

[53] Dagmar Gromann and Maria M. Hedblom. Kinesthetic mind reader: A method to identify image schemas in natural language. In *Advances in Cognitive Systems*, volume 5, pages 1–14, 2017a

the extended repository, a computational blending tool could utilise this information to create a 'cafe' of sorts.

4. Automatic Identification of Image Schemas in Natural Language

The final suggestion for further work is in relation to automatic extraction and identification of image schemas. This has two purposes. The first is to provide empirical support for the members of the image schema repository as demonstrated with the Path family in Chapter 8. The second purpose is based on how the image schemas need to be identified in language before any natural language processing tool could be able to use them. Here machine learning techniques could greatly improve the identification of underlying image-schematic structure for particular expressions. This is tightly connected to the first suggested area of further research area in which humans are asked to annotate objects and events with image schemas, only this time it is done by an automatic system. The biggest problem for automatic systems is how to evaluate the results. Once again crowdsourcing could offer a potential method of getting a large group of people to, with the minimum time consumption, participate in performing the evaluation.

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Appendix A: GitLab Image Schema Repository

All formalisations of the Path family, the Two-Object family and the blending examples have been tested by Hets . For a digital copy of the Appendix, visit: `https://gitlab.com/tillmo/ISL.git`.

```
logic ExtModal

%% the logic ISL, approximated in temporal subsorted first-order logic
ontology ISL =
  sorts Object < Region; Path
  %% flexible op occupies : Object -> Region
       %% implict via subsort above (though technically not sound)
  %% egocentric origin
  rigid op Me : Region
  %% paths
  rigid ops Source,Goal : Path -> Region
  %% RCC8
  rigid preds EC,DC,TPP,NTPP,TPPi,NTPPi,PO,EQ : Region*Region
  rigid preds EC,DC,TPP,NTPP,TPPi,NTPPi,PO,EQ : Region*Path
  rigid preds EC,DC,TPP,NTPP,TPPi,NTPPi,PO,EQ : Path*Region
  rigid preds EC,DC,TPP,NTPP,TPPi,NTPPi,PO,EQ : Path*Path
  %% cardinal directions
  rigid preds Above,Below,Left,Right,Front,Back : Region*Region
  %% QTC
  flexible preds __ ---> __ , __ <--- __ , __ || __ : Object*Region
  rigid pred PP:Region*Region
  forall x,y:Region . PP(x,y) <=> TPP(x,y) \/ NTPP(x,y)
end

ontology ISL_Object =
  ISL then
```

```
  flexible pred Forces : Object*Object
  %% special regions attached to objects
  flexible op inside : Object -> Region
  flexible preds opening_of,cav : Region * Object
end

%% TWO OBJECT FAMILY

ontology CONTACT =
  ISL then
  flexible pred contact : Object*Object
  flexible pred contact : Object*Path
  forall O_1,O_2 : Object . ( contact(O_1,O_2) <=> not DC(O_1,O_2))
  forall O_1 : Object ; p:Path . ( contact(O_1,p) <=> not DC(O_1,p))
end

ontology FORCE_SUPPORT =
  ISL_Object then
  flexible preds Above_support,Force_support : Object*Object
  forall O_1,O_2 : Object . ( Above_support(O_1,O_2) <=>
                                EC(O_1,O_2) /\  Above(O_1,O_2))
  forall O_1,O_2 : Object . ( Force_support(O_1,O_2) <=>
                                EC(O_1,O_2) /\  Forces(O_1,O_2))
end

ontology SUPPORT =
  ISL_Object then
  flexible pred support : Object*Object
  forall O_1,O_2 : Object . ( support(O_1,O_2) <=>
       EC(O_1,O_2) /\  Above(O_1,O_2) /\  Forces(O_1,O_2))
end

ontology ATTRACTION_LINK =
  ISL_Object then
  flexible pred Attraction_link : Object*Object
  forall O_1,O_2 : Object . ( Attraction_link(O_1,O_2) <=>
            Forces(O_1,O_2) /\  Forces(O_2,O_1))
end

ontology GLU_LINK =
  ATTRACTION_LINK and CONTACT then
  flexible pred Glue_link : Object*Object
  forall O_1,O_2 : Object . ( Glue_link(O_1,O_2)  <=>
     contact(O_1,O_2) /\ Attraction_link(O_1,O_2))
```

```
end


%% PATH FAMILY

ontology MOVE =
  ISL then
  flexible pred Move : Object
  forall O : Object . Move(O) <=>
      exists y : Region . O --->  y
end

ontology MOVEMENT_ALONG_PATH =
  MOVE and CONTACT then
  flexible pred movementalongpath : Object*Path
  forall O : Object . forall p : Path .
    (movementalongpath(O,p) <=> Move(O) /\  contact(O,p)
     U (not (Move(O) \/ contact(O,p))))
end

ontology SOURCE_PATH =
  MOVEMENT_ALONG_PATH then
  flexible pred sourcepath : Object*Path
  forall O : Object . forall p : Path . (sourcepath(O,p) <=>
      NTPP(Source(p),O) /\ O <--- Source(p)  /\ movementalongpath(O,p))
end

ontology PATH_GOAL =
  MOVEMENT_ALONG_PATH then
  flexible pred pathgoal : Object*Path
  forall O : Object . forall p : Path . (pathgoal(O,p) <=>
      NTPP(Goal(p),O) /\ O <--- Goal(p)  /\ movementalongpath(O,p) )
end

ontology SOURCE_PATH_GOAL =
  SOURCE_PATH and PATH_GOAL then
  flexible pred sourcepathgoal : Object*Path
  forall O : Object . forall p : Path . (sourcepathgoal(O,p) <=>
     (not Source(p) = Goal(p)) /\
      sourcepath(O,p) /\ pathgoal(O,p)  )
end

ontology SOURCE_PATH_VIA_GOAL =
  SOURCE_PATH_GOAL then
```

```
  flexible pred sourcepathviagoal : Object*Path*Region
  forall O : Object . forall p : Path . forall R : Region . (
      sourcepathviagoal(O,p,R) <=>
      sourcepathgoal(O,p) /\ DC(Source(p),R) /\ DC(Goal(p),R) /\ NTPP(R,p))
end

ontology CLOSED_PATH_MOVEMENT =
  SOURCE_PATH and PATH_GOAL then
  flexible pred closedpathmovement : Object*Path
  forall O : Object . forall p : Path .
    (closedpathmovement(O,p) <=> (Source(p) = Goal(p)) /\
       sourcepath(O,p) /\ pathgoal(O,p))
end


%% DYNAMICS OF CONTAINMENT

ontology CONTAINMENT =
  ISL_Object then
  flexible pred contained : Object*Object
  flexible pred contained : Region*Object
  flexible pred contained : Object*Region
  forall O_1,O_2 : Object . (contained(O_1, O_2) <=> PP(O_1, inside(O_2)))
end

ontology OUTSIDE_OF =
  ISL_Object then
  flexible pred outsideof : Object*Object
  forall O_1,O_2 : Object . ( outsideof(O_1, O_2) <=>
       DC(O_1, inside(O_2)) \/ EC(O_1, inside(O_2)))
end

ontology ON_PATH_TOWARD =
  OUTSIDE_OF then
  flexible pred onpath : Object*Object
  flexible pred onpath : Object*Region
  flexible pred onpath : Region*Object
  forall O_1,O_2 : Object . ( onpath(O_1,O_2) <=>
        (O_1 ---> O_2 /\ outsideof(O_1,O_2)))
end

ontology ON_PATH_FROM =
  OUTSIDE_OF then
  flexible pred onpathfrom : Object*Object
```

```
  forall O_1,O_2 : Object . ( onpathfrom(O_1,O_2) <=>
      (O_1 <--- O_2  /\ outsideof(O_1,O_2)))
end

ontology CONTAINMENT_RELATIONSHIP =
  ON_PATH_FROM and CONTAINMENT then
  forall O_1,O_2,O_3 : Object .
    contained(O_1, O_2) /\ onpathfrom(O_2,O_3) => onpathfrom(O_1,O_3)
end

ontology CROSSING_OPENING =
  ON_PATH_TOWARD then
  flexible pred crossingopening : Object*Object*Region
  forall O_1,O_2 : Object; o:Region . (crossingopening(O_1, O_2, o) <=>
     opening_of(o, O_2)  /\ (onpath(O_1, o)  U  PO(O_1, o)))
end

ontology OPENING_CROSSING =
  ON_PATH_TOWARD then
  flexible pred openingcrossing : Object*Object*Region
  forall O_1,O_2 : Object; o:Region . (openingcrossing(O_1, O_2, o) <=>
     outsideof(O_1, O_2) /\ opening_of(o, O_2)  /\
       (onpath(o, O_1) U PO(O_1, o) ))
end

ontology GOING_IN =
  ON_PATH_TOWARD and CONTAINMENT then
  flexible pred Going_inschema : Object*Object*Region
  forall O_1,O_2 : Object; o:Region .
    ( Going_inschema(O_1, O_2, o) <=>
      onpath(O_1, o) U (PO(O_1, o) U contained(O_1, O_2)))
end

ontology SWALLOWED_BY =
  ON_PATH_TOWARD and CONTAINMENT then
  flexible pred Swallowed_By : Object*Object*Region
  forall O_1,O_2 : Object; o:Region . (Swallowed_By(O_1, O_2, o) <=>
     (outsideof(O_1, O_2) /\ onpath(O_2, O_1))
      U (onpath(o, O_1) U (PO(O_1, o) U contained(O_1, O_2))))
end

ontology GOING_OUT =
  ON_PATH_TOWARD and CONTAINMENT then
  flexible pred Going_outschema : Object*Object*Region
```

```
  forall O_1,O_2 : Object; o:Region . (Going_outschema(O_1, O_2, o) <=>
      contained(O_1, O_2) U (onpath(O_2, O_1)
         U (PO(o, O_1) U outsideof(O_1, O_2))))
end

ontology CONTAINER_LEAVING =
  ON_PATH_TOWARD and CONTAINMENT then
  flexible pred Container_Leaving : Object*Object*Region
  forall O_1,O_2 : Object; o:Region . (Container_Leaving(O_1, O_2,o) <=>
     contained(O_1, O_2) U (onpath(O_2, O_1)
     U (PO(o, O_1) U outsideof(O_1, O_2))))
end

ontology GOING_THROUGH =
  GOING_IN and GOING_OUT then
  flexible pred Going_throughschema : Object*Object*Region*Region
  forall O_1,O_2 : Object;  o_1, o_2:Region .
   (Going_throughschema(O_1, O_2, o_1, o_2) <=>
      opening_of(o_1, O_2) /\ opening_of(o_2, O_2)  /\
      not (o_1 = o_2) /\
      (Going_inschema(O_1,O_2,o_1)
       U (contained(O_1, O_2)
       U (Going_outschema(O_1, O_2, o_2)
       U outsideof(O_1, O_2) ))))
end


%% BLOCKAGE, CAUSED MOVEMENT AND BOUNCING

ontology BLOCKED =
  FORCE_SUPPORT then
  flexible pred blockedby : Object*Object
  forall O_1,O_2 : Object . blockedby(O_1,O_2) <=>
     O_1 || O_2 /\ O_2 || O_1 /\
     Force_support(O_1,O_2)
end

ontology BLOCKAGE =
  BLOCKED and ON_PATH_TOWARD and CONTACT then
  flexible pred blockage : Object*Object
  forall O_1,O_2 : Object . (blockage(O_1,O_2) <=>
      (onpath(O_1,O_2)
       U (blockedby(O_1,O_2)
       U contact(O_1,O_2))))
```

```
end

ontology CM_ENDING_ONE =
  ISL then
  flexible pred purecm : Object*Object
  forall O_1,O_2 : Object . ( purecm(O_1,O_2) <=>
      O_2 <--- O_1  /\ O_1 || O_2)
end

ontology CM_ENDING_TWO =
  ISL then
  flexible pred pursuitcm : Object*Object
  forall O_1,O_2 : Object . ( pursuitcm(O_1,O_2) <=>
     O_1 ---> O_2 /\ O_2 <--- O_1)
end

ontology CM_ENDING_THREE =
  FORCE_SUPPORT then
  flexible pred pushingcm : Object*Object
  forall O_1,O_2 : Object . (pushingcm(O_1,O_2) <=>
      Force_support(O_1,O_2) /\  O_1 ---> O_2 /\ O_2 || O_1 )
end

ontology FULL_CAUSED_MOVEMENT =
  BLOCKAGE and CM_ENDING_ONE and CM_ENDING_TWO and CM_ENDING_THREE then
  flexible pred causedmovement : Object*Object
  forall O_1,O_2 : Object . ( causedmovement(O_1,O_2) <=>
     onpath(O_1,O_2)
     U (blockedby(O_1,O_2)
     U ( purecm(O_1,O_2) \/ pursuitcm(O_1,O_2) \/ pushingcm(O_1,O_2))))
end

ontology TO_BOUNCE =
  ISL then
  flexible pred bouncing : Object*Object
  forall O_1,O_2 : Object . ( bouncing(O_1,O_2) <=>
      O_1 <--- O_2  /\ O_2 || O_1 )
end

ontology BOUNCING_ =
  TO_BOUNCE and BLOCKAGE then
  flexible pred bouncingfull : Object*Object
  forall O_1,O_2 : Object . ( bouncingfull(O_1,O_2) <=>
     onpath(O_1,O_2) U (blockedby(O_1,O_2) U bouncing(O_1,O_2)))
```

```
end

ontology BOUNCING_CM =
  ISL then
  flexible pred bouncingcm : Object*Object
  forall O_1,O_2 : Object . (
    bouncingcm(O_1,O_2) <=> O_1 <--- O_2  /\ O_2 <--- O_1 )
end

ontology FULL_COMBINATION_OF_CAUSED_MOVEMENT_AND_BOUNCING =
  BOUNCING_CM and BLOCKAGE then
  flexible pred Bouncing_CM : Object*Object
  forall O_1,O_2 : Object . ( Bouncing_CM(O_1,O_2) <=>
     onpath(O_1,O_2) U (blockedby(O_1,O_2) U bouncingcm(O_1,O_2)))
end

%% BLENDING EXAMPLES

%% MOTHERSHIP

ontology MOTHER =
  ISL_Object and CONTAINMENT then
  flexible preds Mother,Female,Human : Object; Parent_of : Object*Object
  forall M : Object . ( Mother(M)
       => exists K : Object . exists u : Region . (
               Female(M) /\ Human(K) /\ Parent_of(M,K)
             /\ cav(u,M) /\ contained(u,M)) )
end

ontology VEHICLE =
  CONTAINMENT and SOURCE_PATH_GOAL then
  flexible pred Vehicle : Object
  flexible pred has_sourcepathgoal : Object
  forall O:Object .
      has_sourcepathgoal(O) <=> exists p:Path . sourcepathgoal(O,p)
  forall V : Object . ( Vehicle(V)
       => exists I : Region . (
            has_sourcepathgoal(V) /\  contained(I,V)))
end

ontology SPACESHIP =
  ISL_Object and VEHICLE and CONTAINMENT then
  flexible preds SpaceShip : Object; CargoSpace : Region
  forall s : Object . ( SpaceShip(s)
```

```
       =>  exists C,Space : Region . (
            Vehicle(s) /\ has_sourcepathgoal(s) /\
          contained(s,Space) /\ CargoSpace(C) /\ cav(C,s) /\
          contained(C,s))) %% todo
end

ontology MOTHERSHIP_BLEND =
  MOTHER and SPACESHIP then
  flexible preds MotherShip : Object; DockingPlace : Region
  forall MS : Object . (MotherShip(MS)
      => exists s : Object .exists D,Space : Region . (
           Vehicle(MS) /\ contained(D,MS) /\
           has_sourcepathgoal(MS) /\  DockingPlace(D) /\ cav(D,MS) /\
         contained(MS,Space) /\ Parent_of(MS,s) /\ SpaceShip(s)) )
end


%% SPACESTATION

ontology MOON =
  CONTAINMENT then
  flexible preds Moon,CelestialBody : Object; Consists_of : Object*Object;
        has_shape,revolvearound : Object*Object
        SolarSystem : Region
  op    Spherical : Object
  forall Mo : Object . ( Moon(Mo)
      => exists p,Stone : Object . exists So : Region . (
          Consists_of(Mo,Stone) /\ has_shape(Mo,Spherical) /\
        CelestialBody(Mo) /\ CelestialBody(p) /\ revolvearound(Mo,p) /\
        SolarSystem(So) /\ contained(Mo,So) /\ contained(p,So) ))
end

%% (BLENDED WITH THE MOTHERSHIP FROM THE PREVIOUS EXAMPLE)

ontology SPACESTATION_BLEND =
  ISL_Object and MOON and VEHICLE then
  flexible preds Spacestation,Planet : Object; DockingPlace : Region
  forall Sa : Object . ( Spacestation(Sa)
      => exists p : Object .exists D,So : Region . (
          Vehicle(Sa) /\ Planet(p) /\ SolarSystem(So) /\
          revolvearound(Sa,p) /\ cav(D,Sa) /\  DockingPlace(D) /\
        contained(D,Sa) /\ contained(Sa,So) /\ contained(p,So)) )
end
```

```
ontology MOONSHIP_BLEND =
  MOON and VEHICLE then
  flexible pred MoonShip : Object
  forall MoS : Object . ( MoonShip(MoS)
      => exists So : Region . (
          Vehicle(MoS) /\ has_shape(MoS,Spherical) /\ SolarSystem(So) /\
            contained(MoS,So)) )
end
```

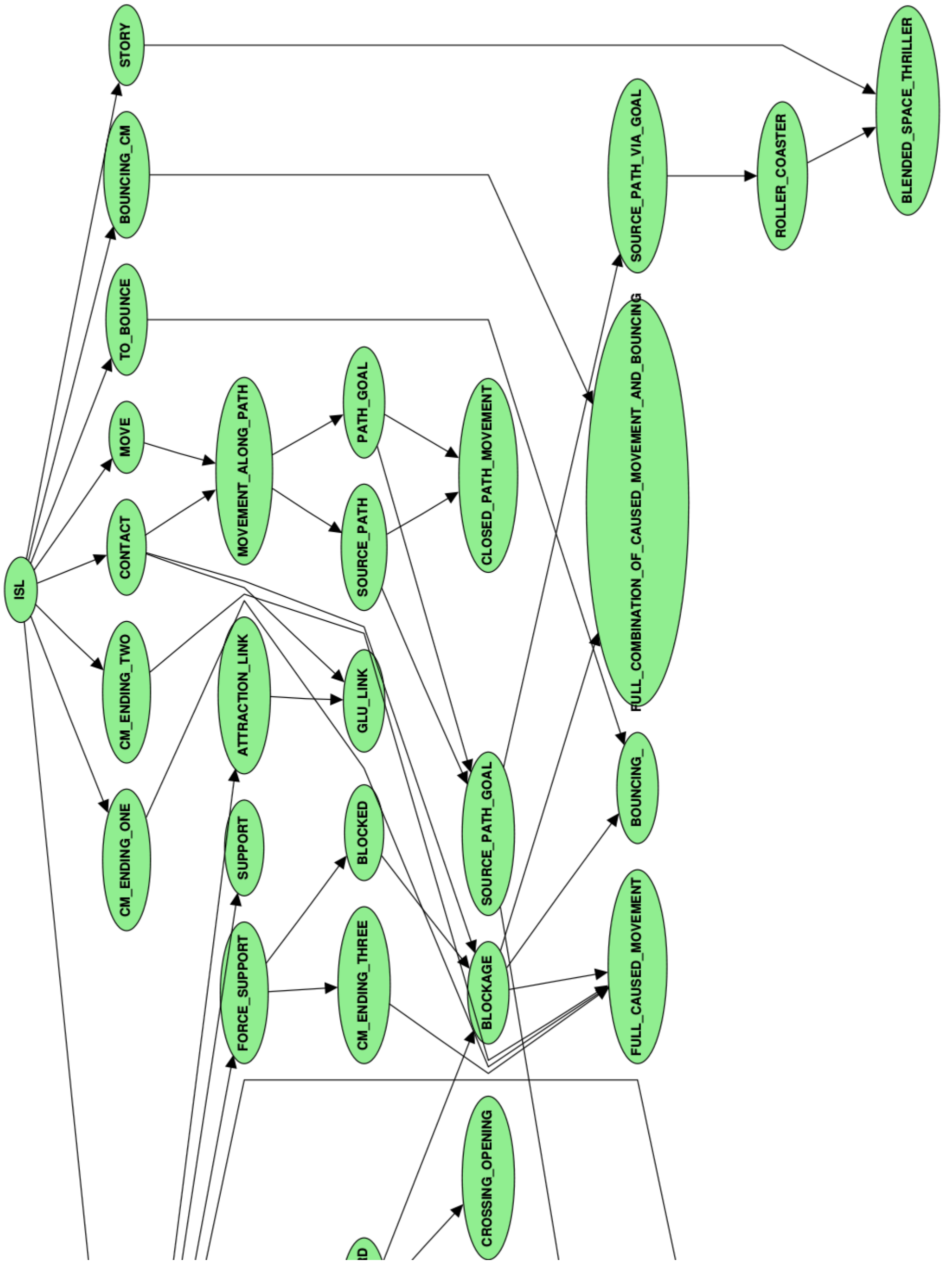

Figure 9.3: The complete repository represented as a theory graph made by Hets. Due to its size it is split into two pictures.

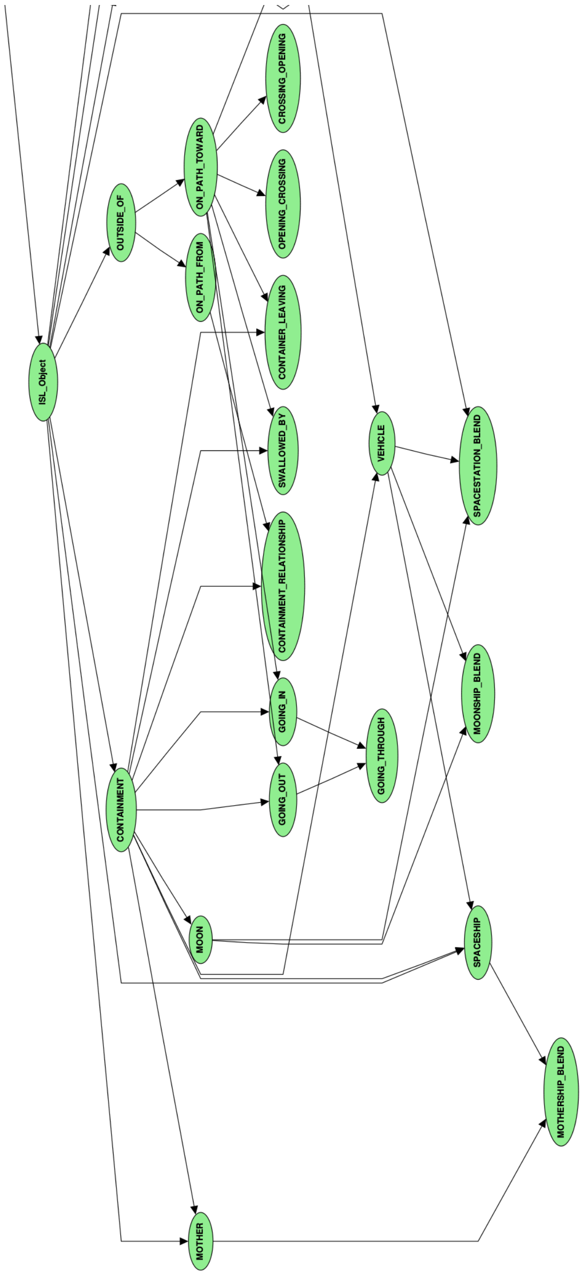

Figure 9.4: The complete repository represented as a theory graph made by Hets. Due to its size it is split into two pictures.

Appendix B: Published and Submitted Articles

The research presented quotes verbatim (in parts or in full) hypotheses, research and results from the publications below. If not otherwise stated, all articles presenting the authors in chronological order do so to acknowledge their equal contribution to the research conducted and presented.

1. Maria M. Hedblom, Dagmar Gromann, and Oliver Kutz. In, Out and Through: Formalising some dynamic aspects of the image schema Containment. In *Proceedings of the 33rd Annual ACM Symposium on Applied Computing*, Pau, France, 2018
2. Dagmar Gromann and Maria M. Hedblom. Body-Mind-Language: Multilingual Knowledge Extraction Based on Embodied Cognition. In *Proceedings of the 5nd International Workshop on Artificial Intelligence and Cognition (AIC-2017)*, Larnaca, Cyprus, November 2017b

The machine learning part of the paper was designed and executed by Gromann.

3. Jamie Macbeth, Dagmar Gromann, and Maria M. Hedblom. Image Schemas and Conceptual Dependency Primitives: A Comparison. In Stefano Borgo, Oliver Kutz, Frank Loebe, and Fabian Neuhaus, editors, *Proceedings of the Joint Ontology Workshops 2017 Episode 3: The Tyrolean Autumn of Ontology*, volume 2050 of *CEUR-WS*, Bolzano, Italy, 2017

Hedblom's contribution was primary conceptual in the role of an experienced image schema researcher.

4. Maria M. Hedblom. Beneath the Paint: A Visual Journey through Conceptual Metaphor Violation. In *Proceedings of the 3rd Joint Ontology Workshops (JOWO)*, CEUR-WS, Bolzano, Italy, 2017
5. Maria M. Hedblom, Oliver Kutz, Till Mossakowski, and Fabian Neuhaus. Between contact and support: Introducing a logic for image schemas and directed movement. In Floriana Esposito, Roberto Basili, Stefano Ferilli, and Francesca Alessandra Lisi, editors, *AI*IA 2017: Advances in Artificial Intelligence*, pages 256–268, 2017
6. Dagmar Gromann and Maria M. Hedblom. Kinesthetic mind reader: A method to identify image schemas in natural language.

The machine learning part of the paper was designed and executed by Gromann.

In *Advances in Cognitive Systems*, volume 5, pages 1–14, 2017a

7. Tarek R. Besold, Maria M. Hedblom, and Oliver Kutz. A narrative in three acts: Using combinations of image schemas to model events. *Biologically Inspired Cognitive Architectures*, 19:10–20, 2017b

8. Dagmar Gromann and Maria M. Hedblom. Breaking Down Finance: A method for concept simplification by identifying movement structures from the image schema Path-following. In *Proceedings of the 2nd Joint Ontology Workshops (JOWO)*, volume 1660, Annecy, France, 2016. CEUR-WS online proceedings

9. Oliver Kutz, Fabian Neuhaus, Maria M. Hedblom, Till Mossakowski, and Mihai Codescu. Ontology Patterns with DOWL: The Case of Blending. In Maurizio Lenzerini and Rafael Pe naloza, editors, *Proceedings of the 29th International Workshop on Description Logics, (DL2016)*, Cape Town, South Africa, 2016.

Hedblom's contribution to the paper was primarily conceptual and found at the initial stages of the paper production.

10. Maria M. Hedblom, Oliver Kutz, and Fabian Neuhaus. Image schemas in computational conceptual blending. *Cognitive Systems Research*, 39:42–57, 2016.

11. Maria M. Hedblom and Oliver Kutz. Shape up, Baby!: Perception, Image Schemas, and Shapes in Concept Formation. In Oliver Kutz, Stefano Borgo, and Mehul Bhatt, editors, *Proceedings of the 2nd Joint Ontology Workshops (JOWO)*, volume 1616 of *CEUR-WS*, pages 59–65, Larnaca, Cyprus, 2016

12. Maria M. Hedblom, Oliver Kutz, and Fabian Neuhaus. Choosing the Right Path: Image Schema Theory as a Foundation for Concept Invention. *Journal of Artificial General Intelligence*, 6(1):22–54, 2015.

13. Maria M. Hedblom, Oliver Kutz, and Fabian Neuhaus. Image Schemas as Families of Theories. In Tarek R. Besold, Kai-Uwe Kühnberger, Marco Schorlemmer, and Alan Smaill, editors, *Proceedings of the Workshop "Computational Creativity, Concept Invention, and General Intelligence (C3GI)*, volume 2 of *Publications of the Institute of Cognitive Science*, pages 19–33. Institute of Cognitive Science, 2015

14. Maria M. Hedblom, Oliver Kutz, and Fabian Neuhaus. On the cognitive and logical role of image schemas in computational conceptual blending. In *Proceedings of the 2nd International Workshop on Artificial Intelligence and Cognition (AIC-2014), Torino, Italy, November 26th–27th*, volume 1315 of *CEUR-WS*, 2014.

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