# Introduction


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In order to help to explain cognition, cognitive structures are assumed to be present in the mind/brain. While the empirical investigation of such structures is the task of cognitive psychology, the other cognitive science disciplines like linguistics, philosophy and artificial intelligence have an important role in suggesting hypotheses. Researchers in these disciplines increasingly test such hypotheses by empirical means themselves. In philosophy, the traditional way of referring to such structures is via *concepts*, i.e. those mental entities by which we conceive reality and with the help of which we reason and plan. Linguists traditionally refer to the cognitive structures as *meanings*—at least those linguists with a mentalistic concept of meaning do who do not think of meaning as extra-mental entities.

The cognitive structures that are discussed in this volume are frames, conceptual spaces, prototypes, cascades, and motor representations of content. *Frames* are the attribute-value structures proposed in lexical semantics by Fillmore (1976) and in psychology by Barsalou (1992a, b). They are closely related to the attribute-value matrices in computational linguistics and knowledge representation in Artificial Intelligence. The notion of *conceptual spaces* refers to the tradition of geometrical

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approaches to meaning started with Gärdenfors (2000). *Cascades* are combinations of frames in a tree, introduced in this volume by Löbner. *Prototypes* are the idea that concepts are defined by typical cases. It is not clear that there are important divisions here. Cascades are a natural extension of frames, as they integrate several frames into a coherent more complex structure; attributes in frames often (or even always) have values in conceptual spaces and the regions defined by concepts within the spaces seem to behave much like prototypes. The *motor representations* are not accessible to introspection and can possibly be defined as frames. It seems encouraging that most of these notions can be connected to each other either by integration or by combination. There is a set of closely related hypotheses that is fine-tuned by reflection, increasing formalization, and connection to an ever widening group of phenomena.

Formal semantics does not aim directly at the cognitive level. It aims at the logical analysis of natural language, using logical relations like entailment and equivalence, and the relation between a predicate and its arguments as a probe into linguistic meaning. Meaning representations in formal semantics are essentially logical formulae for truth conditions. However, there are tendencies to take a closer look at the underlying model-theoretic ontology and provide a more differentiated landscape of things referred to. These developments provide another road of approximation to the cognitive enterprise, as the ontology relevant for natural language semantics is closely related to the way we conceive of the world. The three contributions from formal semantics by Liefke, Krifka, and Morzicky fit in here by introducing agents with a subjective epistemic perspective into the model (Liefke), and arguing for a refined ontology in the models underlying the formal interpretation of natural language (Krifka and Morzicky).

There are in principle two ways of approaching concepts: the extensional way and the intensional way. The extensional way aims at approaching concepts by getting more grip on their extensions, mostly by developing general constraints on concepts and by invoking learning. Formal semantics is the most elaborate representative of the extensional approach as it approaches conceptual meaning from outside; more on the character of formal semantics as opposed to cognitive approaches will be said in the next section. Another example is Gärdenfors' condition of convexity in a conceptual space (used in van Rooij & Brochhagen, Douven, Strößner et al.). In prototype-based accounts of concepts, one can learn a precise criterion for determining whether (or to what degree) an object falls under the concept, without thereby obtaining a conceptual decomposition that would characterize the conceptual content and thus be a properly intensional account of the content.

In a sense, all the experimental psychological contributions belong here: grounding cognitive analysis on behavioral data is an "extensional" approach, as also are approaches based on brain images: Kalenscher et al., Sieksmeyer et al. and Tait et al.

The intensional approach tries to model conceptual content. Here belong the classical approaches to concepts from Aristotle to modern cognitive theories of conceptual representation like Barsalou's frame theory. In this volume it is all frame contributions : Berio, Andreou & Petitjean, Balogh & Osswald, Gamerschlag & Petersen, Löbner, Strößner et al., Taylor & Sutton; Cooper can also be affiliated here.

Umbach & Gust develop an original approach to similarity in which similarity ends up as a strongly context-dependent notion. This can be seen as a concern with the notion of attribute: each perspective under which a and b can be similar is in principle an attribute that applied to a and b returns identical values in some domain. It seems attributes can be made up at will—within certain limits. While this is undoubtedly an intensional approach, it also captures aspects of the geometrical way of thinking.

Several papers discuss the cognitive operations allowed by the structures. In Cooper, this is reasoning over record types with a type logic, in Löbner inferring higher levels in a cascade of frames, in Douven pragmatic reasoning in conceptual spaces. Lexical semantics has always been connected with one special cognitive operation, lexical combination to obtain the meanings of larger units than words. Learning is discussed in Sieksmeyer et al., in Tait et al. and in Taylor & Sutton.

The phenomena and approaches discussed in the papers of the volume and the fields from which they are coming span a wide area. There are philosophical discussions of enactivism (Zipoli-Caiani), the analytic-synthetic distinction (de Almeida & Antal), stereotypes (Strößner et al.), color perception (Berio), perception (Cooper), and implicature (Douven); linguistic semantic approaches to aspect (Fuchs et al.), attitude verbs (Liefke), particles (Balogh & Osswald), non-local readings of adjectives (Morzycki), derivational morphology (Andreou & Petitjean), verbs of movement (Gamerschlag & Petersen), and counting (Krifka). There are psychological studies of pragmatics and the connection between modifiers and movement (Sieksmeyer et al.), rat vocalizations (Kalenscher et al.) and rat reversal learning (Tait et al.). All approaches are relevant to the connected hypotheses mentioned above.

## 1 Cognitive Structures in Natural Language Semantics

The dominant paradigm in linguistic semantics still is the framework of formal semantics; it goes back to Richard Montague's seminal work on the formal analysis of natural language syntax and semantics (Montague 1970, 1973). The semantic component of this framework is a model-theoretic possible-worlds semantics. Lexical and compositional meanings are essentially functions (called "intensions") from the set of possible worlds to appropriate types of entity such as truth values (for sentences), sets of individuals in the universe (for intransitive verbs, common nouns, or one-place adjectives), or sets of sets of individuals in the universe (for quantifiers). The meaning of a sentence is given by its truth-conditions which assign, per possible world, a truth value to that sentence. The criterion of adequacy for semantic analysis is logical adequacy: do the truth-conditions account for all and only those logical entailments a sentence carries?

The approach is cast in classical Cantorian set theory. Notably, the ontology of Cantorian set theory, and consequently of mainstream mathematics, does not know things like concepts—unlike Frege's approach to logics and mathematics. Frege distinguishes concepts and objects, (intensional) sense and (extensional) reference (Frege 1892). Montague grammar is a mathematical model of natural language grammar and meaning in this Cantorian framework. The notion of meaning is a set-theoretical, and therefore extensional *mathematical reconstruction* of Frege's conceptual approach to linguistic meaning, notwithstanding the "conceptual" terminology introduced by Montague, who speaks, for example, of 'intensions', 'properties' and 'individual concepts'. A central point of Montague's approach is a distinction between intensions and extensions, properties and sets, individual concepts and individuals; however, the distinction between the "intensional" object and its extensional correspondent is reconstructed in the a-conceptual framework of set theory: Montague's intensions are just sets of extensions across the set of assumed possible worlds. As pointed out by Thomason in his introduction to the 1974 collection of papers of Richard Montague, "According to Montague, the syntax, semantics and pragmatics of natural languages are branches of mathematics, not of psychology." (p. 2, Thomason, ed. 1974).

As a consequence, there is no simple connection between this semantic theory and psychology. What figures as meanings in formal semantics is nothing that can claim direct psychological reality: Our minds are finite and can handle only finite contents. There are, however, not only infinitely many possible worlds—each possible world itself is a complex of infinite information: all the information necessary to determine for all the infinitely many sentences of a language whether they are true or not. Formal semantics was never meant to provide a psychological model of meaning and semantic composition. It always aimed at capturing the logical side of language: the truth conditions for natural language sentences on the background of "worlds" taken as given, and the logical relations between sentences.

One price that the mathematical, extensional approach to meaning has to pay is fundamental: it can capture the truth conditions, more generally, the logical properties, of a sentence, but these are arguably only a derivative of the underlying conceptual level of meaning. Sentences with different meanings may have identical truth conditions. A logical approach to meaning cannot capture the differences in meaning in such cases. The most conspicuous examples are mathematical and logical truths (*two times three is six*) and analytical sentences true for just semantic reasons (*ducks are birds*) (see the contribution by de Almeida & Antal in this volume). A conceptual analysis in an intensional approach to meaning is able to capture the meanings directly, and with them the differences.

In most varieties of formal semantics, meanings are represented as expressions in an appropriate language of formal logic which is equipped with a rigid model-theoretic interpretation (other approaches formulate the truth-conditions directly). In particular, the meanings of sentences are represented by logical formulae. These formulae serve the primary purpose of formulating the truth conditions of the sentence whose meaning they represent. To give a simple (and grossly simplified) example, the meaning representation of the sentence *some spectators fainted* would be a formula

like '∃x(**spectator**′(x) and **faint**′(x))'. What the meaning representation reflects is that there is existential quantification involved and there are two predications, 'spectator' and 'faint', applied to the same argument. Notably, the parts of the sentence that are explicitly interpreted are the functional element *some* and the predication structure of the sentence; more advanced analyses would also take care of mood, tense and aspect of the verb. Content words, however, the ordinary nouns, verbs, or adjectives, here *spectator* and *faint*, are left unanalyzed.

Formal semantics tries to account for the general rules of semantic composition, and the interplay of syntactic structure with the rules of semantic structure. For the general rules, formal semantics started out with basic logical distinctions between lexical meanings, based on logical properties that are shared by a large number of words, such as whether they denote objects, events, or properties; whether they are used for predication, and what types of arguments they predicate about. These properties constitute the "logical type" of lexical items. Semantic rules of composition essentially describe how the meanings of certain logical types of expressions combine. From this point of view, idiosyncratic differences in lexical meaning, i.e. the precise lexical meanings of individual words, do not, and should not, matter. However, for a deeper understanding of semantic composition, it turns out that one wants to know more about the expressions that combine than their logical type and their syntactic category. In Montague's own papers, he takes care of particular words that exhibit different combinatorial properties than the "ordinary" members of this part of speech. One example is intensional verbs like *rise* in the famous construction *the temperature rises* (known as "Partee's paradox", see Löbner (2020) for discussion). As an intensional verb, or to be precise: in intensional use, *rise* exhibits different logical properties than verbs in extensional use, like *rise* in *the balloon rose to 30,000 m*. The intensional verb predicates about the course, or trajectory, of the temperature function, and thereby about a Montagovian "intension", roughly the intension of the subject NP *the temperature*. By contrast, the extensional verb predicates just about a simple object, i.e. (simply speaking) about the extension of the subject *the balloon*.[1] Montague accounts for the logical difference between the intensional and the extensional construction by meaning postulates, not by analyzing the lexical meanings. Almost fifty years later, we are able to deal with the compositional properties of verbs like *rise* on the basis of a decomposition of their meaning (see the contribution by Gamerschlag & Petersen in this volume). The decomposition explains how the verb meaning interacts with its arguments in different constructions, intensional and extensional, resulting in sense variation of the verb. The analysis of the lexical meaning of the verbs predicts the compositional behavior of this (and similar) verbs.

Natural language semantics, ultimately, needs to provide theories and analysis of lexical meaning, not only of general rules of semantic composition. This is the more so as formal semantics has long since taken a course of constant differentiation, turning to more and more detailed problems, ever closer to the analysis of phenomena that hold only for a small number of words, if not sometimes for a single word. Ideally,

[1] Montague's formal solution is in terms of more complex logical types, but it is logically equivalent to the simplified picture given here.

a theory of semantic composition would start out from decomposition—a description of the structure and content of lexical meanings—and proceed to describe how they combine in a given syntactic construction. The starting point of this endeavor, the analysis of lexical meanings, is, however, an arduous enterprise: there are so many words; each of them potentially with different senses, resulting in hundreds of thousands of lexical meanings in a language like English. Thus, it makes sense to first start out with very coarse semantic distinctions such as the logical type (like 'n-ary predicate expression', 'quantifier', 'logical connective', and so on). Beyond that, most developments of formal semantics have investigated lexical meanings of content words only to a very limited extent.

There are a few exceptional forays by formal semanticists into the realm of lexical meanings, notably Dowty's decomposition of different types of verb (Dowty 1979) which became widely accepted. Otherwise, lexical semantics remained a stepchild of formal semantics; the discipline never came up with a general framework for decomposition. A later proposal for a more general approach to the decomposition of lexical meaning was presented in Pustejovsky's (1995) theory of the "Generative Lexicon". It was extended substantially in many follow-up case studies. The theory proposes a general structure of lexical meanings in terms of four qualia that capture focal properties of the potential referents including form, purpose, origin, along with argument structure and event structure for verbs. The theory models lexical meanings not only of verbs, but also of nouns. The structure of the lexical entries can be considered some variant of frame; Pustejovsky's lexical meanings are, however, considerably more restricted than general Barsalou frames. Pustejovsky's theory of the lexicon is an influential and very important development in linguistic semantics. For many phenomena, it is able to model semantic composition in a much more detailed and differentiated way. This is possible because there is so much more information on the lexical meanings available. Pustejovsky convincingly demonstrated that any detailed theory of semantic composition ultimately needs to be based on decomposition if one wants to better understand how the meanings of the components of a complex expression combine.

However, even with decompositional elements and an apparatus like Pustejovsky's Generative Lexicon, mainstream formal semantics never developed into a psychological (or cognitively oriented) theory of meaning. With the growing influence of cognitive psychology, attempts at connecting linguistic semantics to the facts and theory of cognition have been gaining considerable momentum (see, e.g., Murphy 2002, Chap. 11). This development is in the interest of both semantics and cognitive psychology. If one assumes that linguistic meanings correspond to concepts stored in the cognitive system, then semantic analysis can yield insights into the architecture and mechanisms of the cognitive system, and the empirical investigation of the latter can provide stronger, and different, criteria for adequate semantic analysis.

A theory of linguistic meanings as structures stored or formed in the cognitive system, requires a theory of representations of meanings and concepts in general. One of the goals of the Düsseldorf CRC 991 was to develop a frame theory as a generally applicable theory of representations. The origin and point of departure is Barsalou's theory of frames which he claimed are a candidate for the general format of cognitive

representations (Barsalou 1992a, b). The CRC research has applied Barsalou's frame hypothesis to language, for the modeling of linguistic representations in semantics, syntax, morphology and phonology (see Löbner 2014 for a general discussion of the consequences of the frame hypothesis for the understanding of language). Other scholars applied the approach in their philosophical and psychological research.

Many contributions in this volume take a position with respect to the relationship between meaning and concepts for the issue of decomposition. There's the extreme position argued for by de Almeida & Antal, who argue against decomposition. In their model of natural language semantics, lexical meanings are stored units not to be decomposed, i.e. atoms in the semantic system.

While formal semanticists mostly have practiced lexical atomism by assuming that lexical meanings are just given as they are, they would not argue against decomposition if necessary and feasible. This practice is to be observed in the three formal semantics contributions by Morzicky, Krifka, and Liefke, whose concern is not so much with lexical meanings and their interaction but with the interpretation of certain constructions. Robin Cooper's contribution is in a similar vein as far as lexical decomposition is concerned. He develops a remarkable theory of connecting semantics and cognition and accounting for semantic phenomena with complex cognitive structures, but these structures still contain unanalyzed lexical meanings. At the opposite end of the scale, there are frame-based semantic analyses (Andreou & Petitjean, Balogh & Osswald, Gamerschlag & Petersen, Löbner). These contributions propose frame-based decompositional structures as the basis of modelling semantic composition for a variety of phenomena. Berio applies the frame approach to her discussion of the meaning of color terms.

## 2 Cognitive Structures in Philosophy

In the introductory part on natural language semantics, we sketched Montague's semantics and mentioned Gottlob Frege, one of the founding fathers of philosophy of language and of linguistic semantics in general. Indeed, Frege's notions of *Sinn* (sense) and *Bedeutung* (reference) are what Montague intends to capture with his notions of intension and extension, using Rudolf Carnap's development of possible worlds in, for example, his *Meaning and Necessity* (1947). Moreover, Frege already formulated the central semantic principle of compositionality which we find in Montague and in Alfred Tarski's work on the truth predicate for formal languages (1936). It was also taken up by Donald Davidson (1967) to introduce truth-functional semantics for natural languages: the meaning (truth-conditions for sentences) of a complex expression is a function of the meaning of its parts and the way these parts are put together in the expression. In fact, most of those who built the foundations of formal semantics were not linguistic semanticists, but philosophers, such as Frege, Carnap, Tarski, Davidson, Montague, Lewis or Cresswell, to mention only a few. Barbara Partee and Robin Cooper are among the early protagonists with a genuine linguistic background; Robin Cooper is one of the contributors to this volume. Formal

semantics with its background of analytic philosophy and logic was tremendously important for linguistics because it helped to establish semantics as one of its central disciplines. However, the extensional turn—the replacement of Frege's *Sinn* by the mathematical notion of intension severed the discipline from a conceptual, that is psychological point of view. This made it difficult to connect mainstream semantics to the developments in cognitive science.

The emergence of modern cognitive science is the arrival of computational models within cognitive psychology, models that are inspired by logic, philosophy, linguistics, and artificial intelligence, and required intensive collaboration between logicians, philosophers, linguists, psychologists, and computer scientists. One of these models, of particular influence for many contributions in this volume, is Barsalou's frame model; it "borrows heavily from previous frame theories, although its collection of representational components is somewhat unique".[2] Cognitive structures belong to cognitive science in the sense described above where cognitive science is meant to improve the understanding of human cognitive skills, like categorizing, learning, reasoning and planning, and by developing better and better models of these skills, models that—if they are not directly implemented—clearly could contribute to implementation if existing limitations were removed. Modeling concepts and other cognitive structures is a core enterprise.

Theories of concepts have been central in philosophy for as long as it is practiced as a discipline. One of the most important, if outdated theories is the one found in Locke and Hume, but related to a tradition going back to Aristotle where concepts are identified with images or (pictorial) representations. Another classical view—recently defended again by Peacocke (1992)—takes the necessary and sufficient conditions for the application of a concept to an instance as identity criterion for a concept. A modern alternative to such classical theories is the so-called theory theory of concepts (Gopnik and Meltzoff 1997) in which an analogy is made to the meaning of theoretical terms in scientific theories and in which the content of concepts is given by the theories in which they figure. The exemplar theory of concepts (Brooks 1978) starts from classification learning and defines the extension of the concept as the class of objects which are sufficiently similar to typical exemplars. Rosch (1978) develops a prototype theory of concepts in which objects fall under a concept if they match with a prototype to a certain degree. This view can be related to the family resemblance theory of Wittgenstein. The approach most elaborate on representation is Barsalou's (1992a, b, 1999) frame theory of categorization. For the Düsseldorf CRC 991, Barsalou's frame theory is the central candidate for a theory of cognitive conceptual representations and means of categorization.

The success of cognitive science research also means that improvements in cognitive modelling can lead to new insights within the disciplines that inspired the first versions of the models. In the case of logic and philosophy, the contribution to cognitive science ranges over a number of areas. The development of formalizations of logic for the mathematical study of logic has led to precise versions of notions such

[2] Barsalou (1992a, p. 21). In Barsalou (1992b, p. 158), he mentions various sources from linguistics, artificial intelligence and logic.

as proposition, proof, entailment, contradiction, tautology, validity, completeness, and others that can be used as first models of human inferential and representational skills, to be tested against empirical data.

Alvin Goldman's is a different kind of contribution from philosophy to cognitive science. His theory of human action (1970) turns out to provide a novel general, very far-reaching, model for the cognitive theory of categorization. According to Goldman, human action very often constitutes simultaneous action at many levels. His theory was presented as a contribution to ontology, but in reply to his critics he later stated that it is in fact a psychological theory of categorization (see Löbner's chapter in this volume).

There is an increasing number of philosophers of mind and of language who are themselves cognitive science researchers (or at least follow cognitive science research closely), among them Alvin Goldman (with more recent work), Peter Hanks, Thomas Metzinger, Friederike Moltmann, Albert Newen, Elisabeth Pacherie, Josef Perner, François Recanati, Gottfried Vosgerau and Markus Werning. While this research may be directed at new results or new arguments within ongoing philosophical discussions, it is nonetheless straight cognitive science, even if the questions addressed do not come directly from a psychological cognitive science agenda.

## 3 Cognitive Structures in Psychology

The ability to form conceptual representations has been a core research interest in psychology since the cognitive revolution almost half a century ago. Much of the theoretical and empirical work in cognitive psychology is, and has been, influenced by parallel research lines in philosophy and natural language semantics, some of which are mentioned above. One example is the classic feature list model in cognitive psychology that was developed by Glas & Holyoak (1975) and Hampton (1979). They proposed that each category representation is a list of features, that is, a list of independent representational components forming a single level of analysis, whose sum represents the category. Feature lists treat attributes and values as the same kind and do not specify relations between features. By contrast, as outlined above, frame theory according to Barsalou and others (Barsalou 1992a, 2005) is supposed to be an alternative to flat feature list representations, but also to other theories prominent in the research literature such as prototype theory and exemplar theory. The frame approach holds that concepts can be represented in attribute-value structures. Each attribute can be connected to a cluster of more specific attributes, and certain attributes can also constrain the range of other attributes putting the concepts into dynamic connection and relation. One implication is that the activation of a perceptual property of a concept in frame format may automatically lead to the representation of a whole conceptual system, which allows a structured description of knowledge (Barsalou 2005).

The feature- or attribute-list framework has been hypothesized to be species-general. Referring to the work of Sutherland and Mackintosh (Mackintosh 1965;

Sutherland & Mackintosh 1971), Barsalou already proposed in 1992 (Barsalou 1992a) that not only humans, but non-human animals, too, use attribute-value sets to conceptually represent their world, and he more recently made the claim of a continuity of the conceptual system across species more specific (Barsalou 2005). For example, in a rat version of the set shifting task (Birrell & Brown 2000), animals had to choose between two different bowls where one contained a food reward, and the other did not. The bowls differed in three attribute values: odors, mediums that filled the bowl, and surface textures. One of these attributes cued which of the two bowls contained the reward. Once rats learned to identify the reward-predicting cues, the cue-reward contingencies were shifted. Results showed that learning a novel discrimination was faster in so-called intradimensional shifts when the discrimination was based on the previously relevant perceptual dimension (e.g. odor–odor cue reversals: oregano to cinnamon) compared with a condition when attention had to be shifted to the previously irrelevant dimension in so-called extradimensional shifts (e.g., odor–filling reversals: oregano to sand). The shift-costs, i.e., the post-reversal reacquisition rate, should be identical after intra- and extradimensional shifts if the cue was represented as a feature list. However, this was not the case: the animals were slower to reach pre-shift performance after an extra- compared to an intradimensional shift. This observation is difficult to explain with the hypothesis of isolated feature list representations. A better way to understand these phenomena is that the stimulus is represented by each of its attributes and attribute values, e.g. "odor" with the values oregano or cinnamon. A shift between the values of the same attribute should be easier than a shift between different attributes. The chapter by David Tait, Verity Brown and colleagues in this volume stands in the tradition of this research, and investigates the neural mechanism underlying reversal learning in rats.

It has recently even been argued that frame theory can be extended to understand conceptual representations of animals in the social domain. For example, Gil-da-Costa et al. (2004) studied macaques, and investigated the cognitive and neural representation of social calls emitted by conspecifics. They found that the calls conveyed information about the caller and its socioecological context. There were two types of calls: the first was named *coos* and was associated with positive social context, such as friendly approach behavior. The second type was termed *screams*, which are usually emitted in threatening situations, such as an attack by a conspecific. By using Positron-Emission Tomography, it was found that these conspecific vocalizations elicited activity in neural networks that strongly correspond to the network shown to support the representation of conspecifics and affective information in humans. The chapter by Kalenscher and colleagues in this volume expands on this finding, and argues that conspecifics' calls in rats evoke multi-level representations by carrying acoustic and motivational value; they can, thus, structure rat social interaction.

These examples show that cognitive and comparative research can yield insights into a universal representation system of cognition that applies across species and domains. Hence, bringing together theoretical and empirical work from philosophy, natural language semantics and cognitive comparative psychology bears synergies that either discipline alone could not achieve.

# 4 Summaries

## *4.1 Part I Pushing the Boundaries of Formal Semantics*

This part consists of contributions by formal semanticist, which—in one or the other way—undertake to push the boundaries of present formal semantic theory. They push the boundaries in different respects and in different directions. There is the general challenge to the truth-conditional model-theoretic approach that formal semantics is taking (invariably from its early beginnings until today), that it is intrinsically noncognitive, assuming essentially an idealized omniscient epistemic perspective on truth and truth-conditions. In an early paper on the nature of the Montagovian approach, Barbara Partee posed the question "Semantics—mathematics or psychology?", where she observes that Montague semantics is a mathematical method of doing semantics and modeling meaning; however, she points out, attitude reports seem to require a psychological perspective on their semantic analysis (Partee 1979). We reencounter an aspect of the problem in Liefke's attempt to include the existence of subjective cognitive systems into a wider framework of formal semantic analysis of belief sentences. Counting of various logical types of things has been a challenge to logical analysis and the ontological design of the framework of possible-worlds semantics (cf. Krifka's classical 1990 paper "Four thousand ships passed through the lock: Object-induced measure functions on events"). In Krifka's contribution to this volume, we will tackle with temporary configurations. A different challenge is the assumption of the homomorphism of morphosyntax and semantic composition. It was a central topic since Montague's first treatment of quantification in 1973 which proposed a formal solution to the seeming incongruence of syntactic and semantic structure in the case of nominal quantification. Certain types of seemingly displaced adjectives remain a challenge to date (cf. the paper by Morzicky in this volume).

**Kristina Liefke**'s chapter "A Compositional Pluralist Semantics for Extensional and Attitude Verbs" proposes a new account of linguistic content that reconciles content-pluralism with compositionality. This is achieved by integrating truth-conditional content and attitude report content into a single notion of content. A parametrized version of this notion (with parameters for agents, times, and information states) serves as input to the compositional semantic machinery. By supplying different parameter-values to the parameterized contents of their complements, different verbs select for different components of the complement's integrated content. The resulting account explains the different substitution properties of extensional and attitude constructions and captures the role of agents' epistemic perspective in the determination of attitude content. The account improves upon other accounts of truth-conditional and attitude content (esp. two-dimensional semantics) by interpreting different occurrences of an expression—in extensional and in attitude embeddings—as objects of the same semantic type, and by explaining the substitution-resistance of attitudinal embeddings of extensional constructions.

**Manfred Krifka**, in his contribution "Counting Possible Configurations" deals with entities such as outfits: these consist of a configuration of pieces of clothing; they come into existence when actually combined, cease to exist when not worn, and may or may not come into existence again. To count how many outfits one has is a challenge to formal semantics, as it is often assumed that a requirement for counting objects is that they do not overlap. This condition is violated in cases such as outfits. The article develops an analysis of such configurational entities as individual concepts. It investigates the interaction of noun phrases based on such nouns with modal operators and in collective and cumulative interpretations. The general direction of this paper points towards a theoretical framework in which the objects referred to in language, and consequently, the objects of our cognition, should be seen as individual concepts. The notion of an object contains the ability to identify the same object over different indices, and this is precisely achieved by individual concepts. Some objects are temporally convex in the sense that they have a continuous existence from an initial time to a final time (such as shirts and pants), others have a more spotted existence (such as outfits).

**Marcin Morzicky**'s concern is with cases of adjective constructions that appear to provide notorious problems to the assumption of a match between grammatical and semantic structure. In his paper "Structure and Ontology in Nonlocal Readings of Adjectives", he refers to them as adjectives with "nonlocal" readings, i.e. readings in which the adjective (for example *occasional* or *average*) appears to make the contribution of an adverb. Morzicky points out that the phenomenon is more general than usually assumed. There are two options, he argues, to deal with this kind of phenomenon: to invest into a richer and maybe cognitively more ambitious ontology and to invest in more involved composition rules. As to the intuition that these nonlocal adjective readings are a grammatical oddity, Morzicky concludes: "These adjectives are indeed odd, but in a precise and interesting sense. They are odd in the way that platypuses and lungfish are odd: they are—perhaps metaphorically, or perhaps more than metaphorically—transitional forms in an evolutionary progression, unusual because they combine features of two distinct categories that we normally regard as mutually exclusive."

## *4.2 Part II Concept Theory*

The papers in this section provide more general accounts of how one can approach the nature of concepts from a formal point of view. They deal with very essential questions: Should the meaning of lexical items be approached by means of decomposition/internal analysis or rather be treated as atomic/opaque? How is the concept space structured and what makes a "natural" concept? How is categorization related to perception and which system of types does one have to assume in this regard? What's the impact of language on concepts? The contributions in this section show that these questions—in spite of their classic nature—are at the very heart of present-day research on concepts, meaning and representation.

In their contribution "How Can Semantics Avoid the Troubles with the Analytic/Synthetic Distinction?" **Roberto G. de Almeida** and **Caitlyn Antal** present a criticism of semantic theories that differentiate between analytic and synthetic features, a distinction originally grounded in the philosophical opposition between statements that are logically true and those whose truth depends on additional world/contextual knowledge (Kant 1781; Carnap 1956). In favor of their opinion, de Almeida and Antal discuss potential problems of the lexical decomposition account of causative verbs and the type-coercion analysis of semantic mismatches between verb and argument meaning. As an alternative to these accounts, the authors sketch analyses based on the assumption that concepts invariably contribute all of their contents and do not involve a characterization by features ("concept atomism"). They show how some of the regularities found with causatives as well as type-coercion can be analyzed in terms of inferences/meaning postulates triggered by the meaning of lexical items.

**Leda Berio** discusses the way conceptual representations can be conceived of as being determined by language in her chapter "Linguistic Relativity and Flexibility of Mental Representations: Color Terms in a Frame Based Analysis". She argues that Whorfianism/language relativity on the one hand and universalism on the other hand are extreme oppositions one of which needs not be necessarily assumed given more recent developments which offer a more differentiated, less radical picture of the interrelation between language and concept formation. As a format of mental representation and a device for mediating between linguistic and perceptual information in concepts, Berio proposes frames in the sense of Barsalou (1992a, b) and Löbner (2015). She shows that frame representations exhibit a high degree of flexibility which allows for the representation of the interaction between linguistic and perceptual information necessary to capture the results of experiments related to the relativity/universalism debate, in particular those dealing with color labeling.

Starting from the major division into conventional and conversational implicatures and following subtypologies such as the differentiation between various kinds of scalar implicatures which have developed as some kind of mainstream after the original definition of the term by Grice (1975), **Igor Douven** investigates the conceptual properties of implicatures in his paper "Implicatures and Naturalness". In particular, Douven is interested in the question whether implicatures should be regarded as natural concepts having a reality independent of what he refers to as "linguistic intuitions". The author proposes to deal with that question in terms of Gärdenfors' theory of conceptual spaces (Gärdenfors 2000) and to check whether different kinds of implicatures satisfy Gärdenfors' "Criterion P" that a natural concept is a convex region of a conceptual space. Based on data from a self-conducted study, Douven constructs a conceptual space for different types of implicatures and argues that the distribution of items in the implicature space suggests a characterization of implicatures as natural concepts.

In his chapter "Perception, Types and Frames", **Robin Cooper** offers an approach to perception and categorization formulated within his framework of Type Theory with Records (TTR, Cooper 2012). He claims that perception is determined by the

way we classify entities (i.e. objects and events) according to this framework. Characteristically, TTR goes beyond the traditional binary distinction between entities and truth values put forward by Montague (1974) in building on a more elaborate system of types following the type theory of Martin-Löf (1984). Thus, TTR also assumes basic types for physical objects and events. Cooper gives an introduction to the essentials of TTR with special reference to the conception of "record types" and their instantiation by particular records both of which play a central role within this theory. Moreover, Cooper discusses how his model is related to Fillmore frames and to cognitive frames in the sense of Barsalou (1992a, b) and their formal adoption by Löbner (2014, 2015), Kallmeyer & Osswald (2013) and Kallmeyer et al. (2017) among others.

### *4.3 Part III Conceptualizing Eventualities*

Eventualities are temporal entities, usually understood as comprising events and states both of which have a temporal structure and a location in time. According to Guarino (1997) eventualities can be characterized as 'occurrents' which differ ontologically from 'continuants' defined as objects lacking both temporal location as well as temporal parts while characteristically exhibiting 'mereo-topo-morphological properties'. Both types of entities are closely related to each other such that "occurents are 'generated' by continuants, according to the ways they behave in time" (Guarino 1997: 7). The papers in this section deal with different aspects of eventualities and the way they are conceptualized. Since events are referred to characteristically, but not exclusively, by verbs, all contributions are concerned with phenomena related to verbs such as deverbal nominalizations, verbal aspect, verbal particles and stative readings of dynamic verbs. The last chapter proposes a cognitive structure for representing action, and thereby the meaning of action verbs: the model of so-called cascades. It is based on Goldman's multi-level account of human action that assumes that action more often than never is to be categorized simultaneously at different levels.

In their paper "An XMG Account of Multiplicity of Meaning in Derivation" **Marios Andreou** and **Simon Petitjean** propose an account of the various readings exhibited by English deverbal nouns resulting from *-al*-suffixation. Based on a corpus study, the authors show that apart from an event and result reading *-al* derivatives can display also readings of a non-eventive nature which refer to a variety of participants involved in the event denoted by the base verb. The different readings which are available (or excluded) for a specific verbal base are captured by type constraints which single out particular components in a frame representation of the base verb as referents of the nominalization. One merit of this approach is the reduction of overgeneration, a problem characteristic of monosemous accounts of derivation which assume a general underspecified meaning for an affix. In the final part of their paper, Andreou and Petitjean offer a formalization of their analysis by modelling it using Extensible Metagrammar (XMG, Crabbé et al. 2013).

**Martín Fuchs**, **Ashwini Deo** and **María Mercedes Piñango** discuss the way nonlinguistic constraints determine the use of aspect markers in their contribution "Operationalizing the Role of Context in Language Variation: The Role of *Perspective Alignment* in the Spanish Imperfective Domain." The authors start out from the results of a study on the relevance of the context on the availability of the simple present as a marker of progressive meaning as opposed to the context-independent accessibility of the present progressive marker in three different varieties of Spanish. Fuchs et al. propose an account which builds on a process they call 'perspective alignment'. Perspective alignment aims at bringing the hearer's perspective closer to the speaker's perspective. According to the authors, this process can be considered as mediating between the opposite principles of linguistic economy and linguistic expressiveness. In particular, the progressive interpretation of the simple present in Spanish is only available if speaker and hearer both have perceptual access to the event denoted by the verb which ensures the speaker-hearer perspective alignment in a non-linguistic way.

In "A Frame-Based Analysis of Verbal Particles in Hungarian" **Katalin Balogh** and **Rainer Osswald** provide a formal approach to the semantic contribution of the Hungarian particles *meg-*, *le-*, *el-*, and *fel-* and the way they combine compositionally with their respective verbal base. In their account, they apply a formalization of Role and Reference Grammar (Van Valin & LaPolla 1997) on the one hand and a decompositional frame semantics as a device for combining lexical decomposition with a frame representational format on the other hand. The explicit formalization of the semantic interaction between verbal base and particle sets their approach apart from previous approaches to Hungarian particles which do not elaborate formally on the semantic and syntactic representation of the base verb and the particle and the way they are combined in a compositional semantics. A further aspect addressed by the authors is the syntactic distribution of verbal particles and resultative phrases and how these patterns can be analyzed compositionally by means of frame semantics.

In their paper "On the Fictive Reading of German *Steigen* 'Climb, Rise': A Frame Account", **Thomas Gamerschlag** and **Wiebke Petersen** deal with the stative use of verbs of motion frequently referred to as 'fictive motion' (Talmy 2000). The authors present a case study of the fictive motion reading of the German movement verb *steigen* 'climb, rise' and show how it can be analyzed by contrasting it to the dynamic readings of the verb within a frame account. In particular, they argue that both the fictive motion reading as well as the so-called 'intensional' reading of *steigen* derive from the non-figurative directional reading of the verb since all of these readings obligatorily exhibit a value change restricted to a positive difference. In Gamerschlag and Petersen's frame account, the intensional and the fictional uses result from different operations on the frame representation of the directional use (replacement of the POSITION-attribute in the former case vs. deactivation of the dynamic frame components and accommodation of the meaning of the subject in the latter case).

**Sebastian Löbner**'s contribution "Cascades. Goldman's Level-Generation, Multilevel Categorization of Action, and Multilevel Verb Semantics" proposes a novel theory of the categorization of acts and applies it to the semantics of action

verbs, with fundamental consequences for semantic theory and beyond. The theory is based on Goldman's (1970) multilevel theory of action which is taken here as a theory of categorization. Goldman's central notion is *level-generation*: acts of a type may under circumstances generate acts of other, more abstract, types. The acts form a hierarchical structure that Goldman calls an *act-tree*. Level-generation results in a conceptual relation called *c-constitution* here, i.e. constitution under the given circumstances. Löbner introduces the more general term *cascade* for act-trees. In the second part, multilevel cascade-structure categorization is conflated with a cognitive semantics that models meanings with Barsalou frames. A multilevel analysis of the concept of writing is discussed in depth and detail in order to illustrate the potential and the consequences of a cascade approach to verb semantics. It is shown that the concept of c-constitution can be generalized as to cover the roles of persons and objects across levels in a cascade. The generalization suggests that multilevel categorization may be a very general and fundamental phenomenon in the psychology of categorization.

## *4.4 Part IV Prototypes and Probabilities*

It is a well-known phenomenon that human cognition is able to recognize less-typical specimens as belonging to a particular category although they differ more or less drastically from the perfect representatives of this category (Rosch & Mervis 1975; Rosch 1978). From a theoretical point of view, the challenge in this regard is to capture the relevant cognitive factors underlying the process of categorization and in particular to provide suitable mechanisms able to deal with the non-representative instances of a category. The contributions in this section offer approaches to the categorization and comparison of individuals which deal with the question how the underlying concepts are structured. Characteristically, all of these accounts assume representations of a much more elaborate structure than the feature lists of early prototype theory.

**Corina Strößner**, **Annika Schuster** and **Gerhard Schurz** discuss the effect of modification on prototype compositionality in their paper "Modification and Default Inheritance". Starting from the observation that modification characteristically leads to a decrease of how likely typicality statements are rated, the authors propose an account of prototype composition in adjective-noun combinations as a representative pattern of modification. Their analysis is based on an extension of the selective modification model by Smith et al. (1988). In particular, Strößner et al. add the expressivity of Barsalou frames (Barsalou 1992a, b) which allows for capturing cross-attributional constraints, i.e. co-variation of different attributes of an entity such as the indication of a sour TASTE of an apple by its green COLOR. The formal approach is complemented by an exploratory study in which participants rated the typicality and likelihood of properties of modified and unmodified nouns as well as the typicality and likelihood of particular modifiers of a given noun.

**Samuel Taylor** and **Peter Sutton** present a frame approach to Bayesian models of categorization in their article "A Frame-Theoretic Model of Bayesian Category Learning". They claim that frame representations are advantageous over unstructured feature list representations which are commonly applied in Bayesian models. In particular, Taylor and Sutton argue that it is a shortcoming of the use of feature list representations that they usually depend on supervised training data for assigning weights to features. As an alternative, they introduce frame representations for mediating between sensory input and behavioral output and show that the recursive structure of frames can be exploited in a way which allows for the weighting of attribute values in an unsupervised process of categorization. By analyzing a simple example of animal categorization, the authors demonstrate that attribute values can be weighted in terms of their appearance in the frame: features belonging to attributes closer to the central node of a frame are more important and are assigned more weight than features of attributes located more distant from the central node of a frame.

In their contribution "Extremes are Typical. A Game Theoretical Derivation", **Robert van Rooij** and **Thomas Brochhagen** challenge the hypothesis that a prototype understood as a typical specimen of a category is also a central member of that category. By contrast, the authors claim that rather stereotypes which are defined as extreme exemplars constitute the typical instances of a category. Consequently, although they follow Gärdenfors' (2000) idea that basic categories are always convex sets, they oppose his assumption that prototypes are at the center of a convex set. By discussing color and taste space as basic examples of Gärdenfors' theory of conceptual spaces, Rooij and Brochhagen argue that typical representatives of color and taste are at the edges of the respective spaces and "as far away from each other as possible". In line with their assumption, they propose a game theoretic analysis in which both convexity of meaning as well as stereotypes are accounted for as resulting from principles of rational language use.

In deciding whether an entity belongs to a particular category, similarity of objects plays a central role. In their paper "Grading Similarity" **Carla Umbach** and **Helmar Gust** present an analysis of the German/English similarity expressions *ähnlich*/*similar*, *so*/*such*, and *gleich*/*same* with a particular focus on the explanation of gradability asymmetries (*ähnlich*/*similar* are gradable expressions in contrast to *so*/*such* and *gleich*/*same*). The authors propose an approach to similarity in which the three different expressions of similarity in German and English are treated by means of a similarity relation SIM(x, y, $\mathscr{F}$) with $\mathscr{F}$ being defined as a quadruple comprising the domain of entities, an attribute space, a measure function and a set of classifiers. Umbach and Gust argue that the use of the similarity expressions under discussion can be analyzed by considering in particular the set of classifiers and the different dimensions of comparison which are associated with a specific attribute space. Their account of the gradability of *ähnlich*/*similar* is motivated by ideas originally put forward in Klein (1980).

### *4.5 Part V Cognition and Psychology*

This part addresses the question of cognitive structures from an empirical perspective that applies not only to human cognition, but also to the cognition of rats. Both contributions on rat psychology address basic questions of cognitive structures concerned with cognitive mechanisms that play a role in reinforcement learning. One of the "human" contributions concerns the interaction of language processing with the cognitive motor system. The study differentiates and corroborates the findings on the embodiment of semantic knowledge first reported in Pulvermüller (2005) and in many later studies. The other addresses the radical question whether cognitive representations should be assumed to exist at all.

In their paper "Escitalopram Restores Reversal Learning Impairments in Rats with Lesions of Orbital Frontal Cortex", **David Tait**, **Ellen Bowman**, **Silke Miller**, **Mary Dovlatyan**, **Connie Sanchez** and **Verity Brown** investigate the neural underpinnings and the malleability of cognitive structures. Cognitive structures can be defined as mental models, and they improve the efficiency of information processing by providing a situational framework within which there are parameters governing the nature and timing of information. Tait, Brown and colleagues study cognitive structures by training rats in a reversal learning task where previously acquired stimulus-response contingencies are reversed, and subsequently reverted to the original contingency. Lesions of the rats' orbitofrontal cortex resulted in poorer reversal performance. For example, they showed higher perseveration errors (the rats continued to choose the previously rewarded, now unrewarded cue after a reversal) and took longer to acquire the novel stimulus-response contingencies after a reversal. This impairment in reversal performance was restored to normal performance by administration of escilatopram, an antidepressant drug that increases the synaptic transmission of the neurotransmitter serotonin. In addition, the orbitofrontal cortex lesions resulted in an increase of neuronal activity markers in prefrontal regions, which were even more amplified by escilatopram administration. These results suggest that cognitive structures, enabling learning by representing the world as a cognitive map, involve orbito- and prefrontal brain structures, and can be modulated by serotonergic action.

The contribution by **Tobias Kalenscher**, **Lisa-Maria Schönfeld**, **Sebastian Löbner**, **Markus Wöhr**, **Mireille van Berkel**, **Maurice-Philipp Zech** and **Marijn van Wingerden** deals with rats psychology, too. In their paper "Rat Ultrasonic Vocalizations as Social Reinforcers—Implications for a Multilevel Model of the Cognitive Representation of Action and Rats' Social World", the experimental focus is on prosocial behavior; the second part offers a cognitive modelling of reinforcement learning as cascade formation. The empirical research investigated the role of certain ultrasonic vocalizations (USV) which rats produce at frequencies of either 50 or 22 kHz. The chapter presents evidence supporting the hypothesis that USVs act as social reinforcers. In line with the social reinforcement hypothesis (Hernandez-Lallement et al. 2017), it is shown that rats preferred T-maze compartments associated with 50-kHz USV playback over compartments associated with non-ultrasonic control stimuli. This observation fuels the hypothesis that USVs might orchestrate

and structure social interaction between rats. From the point of view of cascade theory (cf. the contribution by Löbner in this volume), ultrasonic vocalizations with a social "meaning" are assumed to be represented in the rat's brain as two-level cascades with a lower, physical, level of vocalizing and a higher, social, level of signaling. The main application of cascade theory is to the modeling of reinforcement learning, considering it as the formation of a cascade that invests a particular behavior with the aspect of making oneself have a rewarding or aversive experience. This model of learning would explain the acquisition of practical knowledge-how as the result of a basic brain mechanism of cascade formation. This is important in the given context because the same cognitive learning mechanism is very plausibly to be observed with human subjects, too, in their acquisition of the daily knowledge-how. Thus, it appears, cascade formation is a basic brain mechanism across species.

**Jan Sieksmeyer**, **Anne Klepp**, **Valentina Niccolai**, **Jaqueline Metzlaff**, **Alfons Schnitzler**, and **Katja Biermann-Ruben**'s contribution "Influence of Manner Adverbs on Action Verb Processing" aims to investigate motor cortical involvement in the processing of hand- and foot-related action verbs combined with manner adverbs, applying behavioral methods and EEG recordings. The study provides an indication that manner adverbs influence motor behavior while corroborating the already existing data concerning the interaction between action verb processing and motor output. These findings are in line with assumptions made by embodied cognition theories proposing an essential role of sensorimotor areas in the processing and storage of action concepts inherent in action-related language. The adverbial modulation of motor behavior might reflect a certain variation of motor involvement in language processing. This involvement could be susceptible to grammatical constructions modifying the action component of action verbs. Yet, effects of the verb material in a closely matched verb set and influences of timing have to be taken into account.

In his paper "When Mechanical Computations Explain Better" **Silvano Zipoli Caiani** discusses the position of radical enactivism (e.g. Hutto and Myin 2012) whose supporters argue that the representational-computational paradigm does not add explanatory power over and above the physical description of a cognitive system, and therefore should be abandoned. Zipoli Caiani defends the representational-computational paradigm in a careful study of the phenomenon of *optic ataxia*, a disorder characterized by difficulties in executing visually-guided reaching tasks, although ataxic patients do not exhibit any specific disease of the muscular apparatus. He demonstrates that the assumption of the dual stream model of vision—and hence a computational brain mechanism—explains phenomena that the radical enactivism paradigm is unable to account for.

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