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221. The development of Montague grammar

1. Introduction

The term "Montague grammar" denotes, first of all, a particular grammar model developed by the American logician Richard Montague in the late 1960s, early 1970s. In a wider sense, however, it has to come to stand for a more or less loosely connected set of views on doing semantics and on integrating semantics and syntax.

In this article we will first sketch some of the developments in 20th century logic, philosophy and linguistics that form the backdrop of Montague's grammar model and briefly relate his model to contemporary conceptions in both logic and philosophy and in linguistics. Then we will describe the original model of Montague grammar in some detail, isolating two core principles that are responsible for its remarkable and lasting influence. This more systematic section is followed by an overview of the various ways in which Montague's model has been applied, enriched and modified in the period that lasted from the early 1970s until well into the 1980s. Finally, we will briefly review some of the factors that have led to the demise of Montague's original model, and indicate which of its more general principles still survive in its successors.

2. Historical backgrounds

No history of modern semantics, and certainly no history of Montague grammar, can ignore the momentous influence of the works of Gottlob Frege, the German mathematician and philosopher who is also one of the founding fathers of modern mathematical logic. It is no exaggeration to state that much of the work that has been done in linguistic semantics and in philosophical logic since the beginning of the 1920s has built, consciously or unconsciously, on his ideas.

Two of Frege's inventions need to be singled out in this context, viz., the distinction between 'sense' ["Sinn"] and 'reference' ["Bedeutung"], and the principle of compositionality.

Fregean sense and reference. In his seminal paper "Über Sinn und Bedeutung" (1892, reprinted in Frege 1962), Frege argues that a proper account of the cognitive meaning of natural language expressions requires a distinction between the sense of an expression and its reference. Every expression refers to something external to language: an object, a property or a relation, an event or a situation. But its reference does not exhaust an expression's meaning, as, for example, reflection on the meaning of identity sentences reveals. If such a sentence, say "A = B" is true, then the reference of A equals that of B. Yet, Frege notes, a true identity sentence need not be tautological, on the contrary, it can be quite informative. This is due to expressions not just having a reference but also a sense, which Frege characterizes generally as "the way in which the reference is given" ["die Art des Gegebenseins"]. Descriptions provide suitable examples: "The first man to set foot on the surface of the moon" and "the commander of the Apollo 11 mission" refer to one and the same man, yet characterize this individual in different ways. Hence a sentence that asserts the identity of the reference of the first description and that of the second can be informative.

Frege extends the sense−reference distinction to other categories of expressions: predicates and relations, and sentences. His treatment of sense and reference of predicates and relations is somewhat complicated (see his "Funktion und Begriff" (1891) and "Über Begriff und Gegenstand" (1892), both reprinted in Frege 1962.) He makes an ontological distinction between properties as abstract objects, referred to by complex terms such as "the property of being a horse", and the referents of expressions which are actually used in a predicative manner, such "is a horse" as a constituent of a sentence such as "Pegasus is a horse". According to Frege these expressions refer, not to properties, but to what he calls "unsaturated objects", i.e., to objects which need to combine with another object, in this case an individual, to form a complete thought.

A thought, then, is what constitutes the sense of a sentence. As such it is constituted by the senses of the expressions occurring in the sentence. This explains, for example, why the identity statement expressed by "A = B" may differ in cognitive value from the one expressed by "A = A". The latter is tautologous, and hence uninformative, whereas the former, as we just saw, can be informative, even when true. The difference between these two sentences is explained by Frege in terms of their respective sense, i.e., in terms of the thoughts they express. The thought expressed by "A = B" differs from the one expressed by "A = A" because the former is composed of the sense of "A" and the sense of "B", whereas the latter involves only the sense of "A". (And, of course, both contain the sense of the identity.)

Frege's sense−reference distinction reinstates, to a certain extent, a much older one, viz., that between the intension and the extension of a predicate. However, his analysis extends the tradition in two important ways. First of all, he does not limit the sense−reference distinction to predicates, but applies it across the board, i.e., to expressions of all kinds of categories. Of course, most syntactic categories contain, besides lexical elements, complex expressions. And some categories, e. g., that of sentences, do not contain any lexical elements at all. In order to assign senses to complex expressions in a systematic way, Frege extends the tradition in another way and assumes that complex senses can be built up from simpler ones in a step-by-step, syntax driven fashion. (Whether Frege actually *stated* this compositionality principle explicitly is subject of debate. For present purposes we may sidestep this discussion: the compositionality principle of sense, if not explicitly endorsed by Frege, is certainly implicitly presupposed by many of his arguments, and in one form or another has deeply influenced modern theories of meaning.)

Fregean compositionality. Here we touch on a second element of Frege's thought that has shaped modern thinking and theorizing about meaning and semantics, viz., the idea that the meaning of a complex expression is determined by that of its constituents parts and the particular way in which these constituent parts are combined to form the complex whole.

The idea of defining the interpretation of complex expressions in a stepwise fashion, following their syntactic composition, lies at the heart of Frege's earliest work, the famous *Begriffsschrift* of 1879. Here Frege applies it, not to natural language expressions, but in the construction of a formal language. One of the challenges Frege takes on in the definition of his "conceptual notation" is that of giving a proper analysis of relational sentences with multiple quantified arguments, e. g., sentences of the form "for all x there exists a y such that Rxy". If one allows relations with an arbitrary number of arguments, the number of quantifier combinations is arbitrary as well, and hence cannot be specified and interpreted in advance. Therefore, the interpretation of such combinations has to be characterized in some other way. Frege's fundamental insight here was to marry interpretation with syntax: the step-by-step syntactic construction is mirrored in a similar step-by-step interpretation process. To each step in the syntactic construction process corresponds a semantically significant operation: the application of a function to its arguments, the introduction of a connective, or that of a quantifier. Every constituent expression hence has a interpretation of its own, and the interpretation of the entire formula, however complex, is determined by the interpretations of its constituent parts, as required.

Grammatical form versus logical form. In the *Begriffsschrift* Frege develops a formal notation, that is intended as an improvement of natural language as a tool for scientific analysis, in particular for use in mathematics and philosophy. Hence Frege makes a distinction between formal languages on the one hand and natural languages on the other. The former have a rigorously defined syntax and semantics, something that the latter lack. Natural languages, in some respects at least, do not display the logical forms needed for unambiguous representation of thoughts and inferential relations. If such is our aim, Frege holds, we need to distinguish between grammatical form and logical form and bring out the latter in a formal language suited for the kinds of representations and inferences we are interested in.

Thus Frege postulates a fundamental distinction between natural and formal language, one that has deeply influenced the philosophical outlook on language for a considerable time, in fact well into the 1960s. So here is a Fregean idea that did *not* serve as a precursor of Montague grammar and other modern semantic theories: obviously, the idea of natural language being vague and unsystematic does not invite application of formal methods.

This idea of a rift between natural and formal language has been a mainstay of both logical positivism and ordinary language philosophy, the two main branches of 20th century analytical philosophy. Of course, the conclusions they derived from it are different. Logical positivism favored the construction of formal languages as tools for philosophical analysis, whereas ordinary language philosophy concentrated on detailed, but informal descriptions of the various ways expressions of natural language are used. Both, however, rejected the idea of a formally explicit analysis of natural language itself, and for similar reasons. In philosophical and mathematical logic, too, this preconception of the nature of natural language remained dominant for a long time. (A notable exception was Hans Reichenbach, who as early as 1947 developed logical analyses of various classes of natural language expressions, that are not only detailed and systematic, but also very sophisticated. His theory of verb tenses, for example, is still one of the most influential around.) For example, when Tarski developed his theory of truth in the 1930s he quite explicitly stated that such a formal theory can be applied to formal languages only, and never to natural language, in view of the fact that the latter's syntax does not allow for the required rigorous formal characterization (Tarski 1944).

All in all Frege's heritage as accepted by his immediate successors is a mixed blessing. His ideas on sense and reference are developed directly in conjunction with analysis of natural language, but these remain informal, and the distinction itself, as far as natural language is concerned, is never developed in a systematic and formal fashion. Frege's sharp distinction between formal and natural language is of course one of the main obstacles here. Initially, compositionality is introduced in the context of Frege's development of his "conceptual notation", i.e., with regard to the interpretation of formal languages. However, it is also obviously present in his later informal work on natural language and the sense−reference distinction.

So other developments, too, were needed in order for logical approaches to come to fruition in the domain of natural language. First of all, the idea of natural language being too vague and unsystematic to lend itself to rigorous formal treatment had to be upturned. Secondly, Frege's sense−reference distinction needed a formal machinery to become applicable in a systematic way. And thirdly, additional logical tools were needed in order to apply the idea of compositionality to natural languages, which have a much richer structure than the formal languages of logic.

The Chomskyan Revolution. Probably the most significant development in 20th century linguistics, and one without which Montague Grammar would not have been possible, is the rise of the Chomskyan paradigm. The idea of describing and explaining natural languages by means of the same kind of formal grammars that are used in the definition of formal languages, was a radical change, and one that caught on quite rapidly. Already before the appearance of Chomsky's *Syntactic Structures* in 1957, some philosophers proposed to wed formal syntax with the machinery of logic in order to capture both form and meaning. The suggestion did not get a favorable reception by the linguists, however (Bar-Hillel 1954, Chomsky 1955), and it took the logicians and philosophers more than a decade to develop these ideas into working theories. It took even longer for the idea of a formal, logical approach to semantics of natural language to gain a firm foothold in mainstream linguistics, and even then it caught on mainly outside the Chomskyan tradition, in which it never gained any real following. However, be that as it may, Chomsky's work did pave the way for the logical approach in semantics, since it showed the logicians and philosophers that their traditional assumption that natural language is too unsystematic and too vague to lend itself to formal treatment, is unfounded.

Possible Worlds Semantics. Another important development that had to take place in order for Frege's ideas on sense and reference to become applicable in actual systematic descriptive and explanatory theories, was that of possible world semantics. Originally, possible worlds semantics was conceived of as a model theory for modal and intuitionistic logic, in the pioneering works of Stig Kanger, Jaakko Hintikka, and Saul Kripke. Soon, however, its scope was extended and it became the primary analytic tool for dealing with all kinds of intensional concepts in a formal way. In particular the Fregean sense−reference distinction proved to lend itself to formal reconstruction in this conceptual framework.

Assuming a set of possible worlds, references of appropriate kinds are assigned to expressions in each world. Thus, a term is assigned an object as its referent in a world, a predicate a set of such objects, an n-place relational expression a set of ordered n-tuples of objects, and sentences are assigned truth values in worlds. Much of this is familiar from ordinary modeltheoretic semantics. By relativizing reference to possible worlds, however, we also avail ourselves of the functions that maps worlds to these references. Thus an individual concept expressed by some term is a function from worlds to objects. Similarly, a property is conceived of as a function from worlds to sets of objects, and an n-place relation as one that links worlds with a set of n-tuples. A proposition, finally, is a function from possible worlds to truth values. Such intensional notions as that of an individual concept, a property and a relation, and of a proposition, are sufficiently like Frege's various types of senses to be used as formal counterparts thereof.

Modal operators are analyzed in terms of quantification over possible worlds. To give a simple example, a formula of the form $\Diamond\varphi$

(read as "It is possible that φ") is true in a possible world w if and only if there is some suitable world w' such that φ is true in w'. Depending on the kind of possibilities one takes the set of possible worlds to embody, this gives an analysis of various kinds of modalities: alethic, epistemic, deontic. The kind of modality we are dealing with, may put additional constraints on the possible worlds and the relations between them. For example, if we read $\Diamond$ as an alethic modality (i.e., as "It is possibly true that …"), then we would want $\varphi \rightarrow \Diamond\varphi$ to be a valid priniciple: Whatever is actually true, is possibly true. But if we read it as a deontic modality (i.e., as "It is allowed that …"), we would want the same formula not to come out valid: it is not plausible that whatever is the case, is therefore allowed.

Typed λ-Calculus and Categorial Grammar. Possible world semantics was developed in the context of modal propositional and predicate logics, systems which employ languages that from a syntactic perspective are relatively simple. Natural languages, of course, are much more complex.

First of all, they have more extensive and varied vocabularies, i.e., natural languages contain many more types of expressions than just predicates, terms, and connectives and quantifiers. There are adjectives and adverbs, prepositions, nouns and verbs, personal pronouns and demonstratives, temporal and aspectual expressions, singular and plural forms, and so on. Moreover, within each category there are semantically distinguishable subcategories, such as mass nouns and count nouns, activity verbs and stative verbs, intersective and subsective adjectives.

Secondly, natural languages have a different, more complex constituent structure. One example is provided by the various ways in which relations are expressed. Where in logical languages all the arguments in a relation are on equal footing, many natural languages distinguish between the subject and direct object (and indirect object) arguments by assigning them different structural positions. Frege's fundamental insight was that for logical purposes a distinction between subject and object is not necessary. Seeing no way to reconcile that with the fact that natural languages nevertheless treat them differently, he concluded that logical form and grammatical form are different. If one wants to apply the tools of logical semantics to natural language without falling back to some kind of language reform, this is a problem that has to be solved. Basically the problem is how to satisfy Fregean compositionality for natural languages with their rich and diverse syntactic structures: every syntactic constituent needs to be assigned a meaning in such a way that it depends on the semantic contribution of its constituent parts. And the stock of semantic objects to go around (individual concepts, properties, propositions) isn't large enough: we need ways of building other, complex types of semantic objects from these basic ones.

Other inventions in logic come to the rescue here, viz., that of the typed λ-calculus, originally developed by Alonzo Church (Church 1940) and, closely related, that of categorial systems, pioneered by Kazimierz Ajdukiewicz (Ajdukiewicz 1935). Typed λ-calculus is an abstract system for studying functions and their properties, such as computability and decidability. It has connections with the kind of categorial systems, of what he himself called "semantic categories", that Ajdukiewicz developed at more or less the same time. Both provide us with tools that allow us to treat more complex structures of a greater variety than the usual logical languages display, and in such a way that the syntax and the semantics are treated simultaneously. Therein lies their usefulness for natural language analysis.

But Church's typed λ-calculus was not developed with application to natural languages in mind. (However, in Church 1951 he used similar ideas to give a reconstruction Frege's ideas on sense and reference.) And although Ajdukiewicz' original work did concern itself with language, it did so mainly from an epistemological perspective, not with an eye to application in linguistic analysis. (An early attempt to use categorial grammar to analyze natural language syntax is Lambek 1958.) So it really took a combination of various insights to bring out the potential for natural language semantics.

Logical Grammar as a Synthesis. These divergent developments in logic, philosophy and linguistics came together in the late 1960s, when several philosophers and logicians started to realize that all the necessary tools for developing a systematic and formal semantics for natural language were available. Thus the idea of a logical grammar for natural language was born. Of course, different authors, often starting from diverging philosophical principles, conceived of such a grammar in different ways. Donald Davidson, for example, following Quine eschewed the use of intensional notions and proceeded to define an extensional, truth-conditional semantic theory (Davidson 1967). But the very idea that such an enterprise was possible, was widely shared. As Davidson and Harman stated (in their preface to a seminal collections of papers, Davidson & Harman 1972), referring to formal semantics as the emerging interface between logic, linguistics and philosophy:

> We trust it will be agreed that there is more to this than the usual business of rubbing two or more disciplines together in the expectation of heat and the hope of light. In the present case, a common enterprise already exists; our aim is to make it a cooperative one.

Among the entrepreneurs of logical grammar was Richard Montague, whose work proved to have a special impact on the field. This is only partly due to its general and rigorously systematic character. What really distinguished his work from that of other pioneers, is that Montague was not satisfied with giving either the general outlines of a semantic theory, or a detailed semantic analysis of a particular phenomenon. He wanted to show how such a formal semantics could be incorporated in the grammar of a natural language, i.e., he insisted that a proper account of the relationship betweens semantics and syntax was an essential ingredient of the enterprise. And Montague illustrated his general ideas with actual, detailed analyses of important aspects of natural language syntax and semantics, such as quantification and structural ambiguity, adjectival modification, intensional verb phrase constructions.

He did so in a series of papers, among which "Universal Grammar" (1970), "English as a Formal Language" (1970), and "The Proper Treatment of Quantification in Ordinary English" (1973) were the most influential. (Along with several others, these papers have been collected in Montague 1974.) The first paper contains a very abstract, algebraic formulation of his ideas. The latter two are concerned with applications to fragments of natural language, each giving a specific model of how such an application may proceed. The main difference is that in "English as a Formal Language" Montague defines an interpretation for the expressions in the fragment of English *directly*, by connecting them with modeltheoretic semantic objects, such as individual concepts, properties and propositions. In "The Proper Treatment" paper Montague takes an indirect route. Here expressions of English are interpreted *indirectly*, by translating them into expressions of a logical language that is semantically interpreted in the usual way. It is the model of the last paper, commonly referred to as "the PTQ-model", that has become the standard format of Montague Grammar. And it is therefore this model that we will take a closer look at in the next section.

3. Montague's original model

General Structure. The PTQ-model consists of a categorial syntax of a fragment of English, a logical language, that of intensional typed λ-calculus, a modeltheoretic semantics for that language, and a definition of a translation function from the expressions generated by the categorial syntax into expressions of the logical language. As said, the former expressions are interpreted indirectly, through translation into the interpreted expressions of the logical language:

$$\boxed{\text{Natural language}} \xrightarrow[\text{translation}]{} \boxed{\text{Logical language}} \xrightarrow[\text{interpretation}]{} \boxed{\text{Models}}$$

Fig. 221.1: Indirect interpretation in the PTQ-model

The principle of compositionality is implemented in this model at two points. The interpretation of the logical language transpires in the usual manner. First the notion of a model for the language is defined. Models contain the semantic objects that can be expressed by the language, and an interpretation function that assigns appropriate objects to the basic expressions. Secondly, the interpretations of complex expressions are defined in a way that parallels the rules of the syntax that generate them. For every syntactic rule that operates on expressions $\alpha_1 \dots \alpha_n$, to yield an expression γ there is a clause that defines the interpretation of γ in terms of the interpretations of $\alpha_1 \dots \alpha_n$. If the syntactic rule introduces syncategorematic expressions, such as connectives, quantifiers, or sentential operators, their interpretation is implicitly defined in the corresponding clause. This is the usual way of specifying the semantics of a formal language, that actually is not strictly compositional in view of the way in which syncategorematic expressions are introduced and interpreted, but which is compositional in spirit, and can be made to comply with strict compositionality.

The second point at which compositionality comes into play is with the translation of the natural language into the logical language. In order to transfer the compositional interpretation of the latter to the former, the translation process has to meet certain requirements as well. Given a translation of lexical elements of the natural language into simple or complex logical expressions, every syntactic rule that derives complex expressions is matched with a translation rule that defines the translation of the derived, complex expression in terms of the translations of the constituent parts. In the natural language syntax, too, Montague allows for rules which introduce syncategorematic material, but, again, such rules could in principle be eliminated. Notice also that there may be syntactic rules which do not affect the meaning, here the corresponding translation rule is simply an identity map.

In his "Universal Grammar" Montague analyzes the syntax of the two languages and the models used in the semantics as algebras. The translation and interpretation components in this model then show up as homomorphic mappings. Translation is a homomorphism from the syntactic algebra of the natural language into the syntactic algebra of the logical language, and interpretation is a homomorphism from the latter into the algebra of semantic objects. Since the composition of any two homomorphisms is again a homomorphism, the two-step process of figure 1 indeed defines an interpretation for the natural language expressions. Actually, it shows that the indirect and the direct approach are equivalent, and that the intermediate translation step is there for convenience's sake, not because it is necessary.

Let us now take a closer look at the three components of a PTQ-style Montage grammar: the categorial syntax, the language of intensional type theory, and its semantics. (The following presentation is slightly simplified at some points. See Dowty et al. 1981 and Gamut 1991 for extensive introductions.)

Categorial Syntax. A categorial syntax for a particular (fragment of) a language consists of a specification of:

- a set of categories, in terms of basic categories and derived categories;
- a set of syntactic rules, that determine how expressions of various categories can be combined;
- an assignment of categories to the lexical expressions of the language.

PTQ's categorial syntax has three basic categories: S, for sentences, CN, for common noun phrases, and IV, for intransitive verb phrases. Complex categories are defined as follows:

> if A and B are categories, then so are A/B and A\B

with A/B the category of expressions that combine with an expression of category B to their right to form an expression of category A, and A\B that of expressions which take an A to their left to form a B. This type of categorial system is called "bi-directional". Examples of derived categories are: T = S/IV, of terms; TV = IV/T, of transitive verbs, IV/S, of sentential complement verbs; CN/CN, of pronominal adjectives.

In a simple categorial syntax there is only one syntactic rule, that of concatenation of expressions of matching categories. Thus a sentence S is the result of combing a T = S/IV with an IV. And an IV may be either lexical, or derived, e. g., the result of combining a TV = IV/T with a T.

In the categorial syntax of PTQ syntactic rules do more than concatenate. For example, there are rules that introduce determiners syncategorematically. There are lexical elements of category T, viz., proper names and pronouns, but also complex expressions consisting of a determiner and a (lexical or complex) common noun. In the PTQ-model these T's are not derived by combining a lexical determiner, that would be of category T/CN, with a CN, but by a special rule, that introduces the determiner in question syncategorematically.

Other examples of syntactic rules that do more than simply concatenate, are Montague's "quantification rules". These rules combine terms with sentences that contain an occurrence of a special, variable expression of category T to form new sentences, and are introduced to deal with scope ambiguities. Thus a sentence such as "everyone admires someone" has two derivations corresponding to the two relative scopes of the quantified terms "everyone" and "someone". The first is the so-called 'direct derivation', that results from a straightforward combination of "admires", of category TV = IV/T, with "someone", a T, to form the complex IV "admires someone", that combines with the T = S/IV "everyone" to form the sentence. As will become apparent shortly, the interpretation of this derivation is the one in which "everyone" has scope over "someone". The other derivation, called the "indirect derivation" first derives the S "everyone admires him_0", with "him_0" a variable T, and then combines this with the T "someone". The semantic result is that "someone" now has scope over "everyone". The same mechanism is used to account for so-called "de dicto − de re" ambiguities, such as occur in a sentences like "John is looking for an assistant".

The occurrence of this type of syntactic rule makes clear that translation (and, hence, interpretation) operates not on strings, or on constituent trees, i.e., labeled strings adorned with categories, but on so-called 'derivation trees', i.e., strings with their derivational history, including category information.

Intensional Type Theory: Language. The second component of a PTQ-style Montague grammar is the logical language into which the natural language expressions are translated. This is the language of intensional type theory, with λ-abstraction.

All expressions belong to a type. Basic types are *e*, for expressions which denote objects; *t*, for expressions which denote a truth value, i. e. for sentences; and *s*, a special type used to account for intensional expressions. From this set of basic types complex types are derived: if *a* and *b* are types, than $<a,b>$ is a type, and if *a* is a type, then so is $<s,a>$. Complex types are *functional*: an expression of type $<a,b>$ is one that combines with an expression of type *a* to form one of type *b*. Examples are $<e,t>$, of one-place predicates; $<e, <e,t>>$, of two place predicates; $<<e,t>, <e,t>>$, of predicate modifiers; and so on. Expressions of types $<s,a>$ are also functional, but in a special way, since there are no expressions of type *s* that could be their argument.

The language contains constants and variables of the various types, and the usual connectives, quantifiers and intensional operators, such as modal and tense operators. In addition it features two operators, ^ (often called "cap") and ˅ (called "cup"). The cap-operator turns an expression of any type *a* into one of type $<s, a>$. The cup-operator only takes expressions of type $<s, a>$ and turns them into expressions of type *a*.

Another essential ingredient of the language is λ-abstraction. From any expression α of type *b* and variable *x* of type *a*, we can form the expression: $\lambda x\ \alpha$, of type $<a, b>$. So, λ-abstracts are also functional expressions. As will become clear shortly, λ-abstraction is an important tool for translating, and hence interpreting, complex expressions of various categories.

Intensional Type Theory: Semantics. The semantics of the language of intensional type theories consists, as usual, of a definition of suitable model structures and of a definition of the interpretation of the expressions of the language in these models.

Unlike more standard languages, the language of intensional type theory contains expressions of a great many types, each of which is to be interpreted in a suitable domain. The basic types *e, t*, and *s* are associated with a set D of individuals, a set {0,1} of truth values and a set W of possible worlds. A functional type $<a,b>$ is associated with the set of functions from the domain D_a to the domain D_b. For example, an $<e,t>$ expression, i.e., one-place predicate, denotes a function from D_e to D_t, i.e., from D to {0,1}: (the characteristic function of) a set of individuals. And a predicate modifier, i.e., an $<<e,t>, <e,t>>$ type expression, denotes a function from functions from D_e to D_t, to functions from D_e to D_t. The intensional types $<s,a>$ are linked to functions from W to D_a, i.e., functions from possible worlds to objects of type *a*. For example, an expressions of type $<s,t>$ denotes a function from possible worlds to truth values, i.e., a proposition. Similarly, an expression of type $<s, <e,t>>$ denotes a function from worlds to sets of individuals, i.e., a property.

A model M consists of some hierarchy of domains generated by sets D, W, and {0, 1}, and an interpretation function I that assigns suitable denotations to the basic expressions: if α is a basic expression of type *a*, $I(\alpha) \in D_a$. Likewise, an assignment g takes variables *x* of type *a* into the corresponding domain. The definition of the interpretation of the language then follows the definition of the syntax. Every expression is interpreted relative to some world w and assignment g.

Concatenation of expressions is interpreted as function application. If α is of type

$<a, b>$ and β of type a, then $\alpha(\beta)$ is of type b. The interpretation of $\alpha(\beta)$ is obtained by applying the interpretation of α, a function from D_a to D_b, to that of β, an object in D_a, the result being an object in D_b. The interpretations of the connectives, quantifiers and intensional operators follows the usual patterns. The operation of λ-abstraction semantically amounts to functional abstraction: if α is of type b and x of type a, $\lambda x\alpha$ is interpreted as that function from D_a to D_b that, applied to some $d \in D_a$, returns the interpretation of α with d assigned to x. The semantics of the cap-operator ^, too, is functionial abstraction: $^\wedge\alpha$, with α of type a, denotes that function from W to D_a that applied to some $w \in W$ returns the interpretation of α with respect to that world. I. e., the cap-operator abstracts over the world parameter in interpretation, and hence forms a function that gives the interpretation in each world. Thus expressions of the form $^\wedge\alpha$ denote Fregean senses. Correspondingly, the cup-operator $^\vee$ semantically amounts to application of such a sense-function to a world: in a world w: $^\vee\alpha$ denotes the value of the function α in w.

Given the semantics, a logic results, i.e., a set of entailments that hold among the formulae of the language. One of these merits special attention in the present context, viz., the principle of λ-conversion. Given certain restrictions on β, viz., that it be "semantically closed", and provided no variable clashes occur, it holds that:

$$\lambda x\ \alpha(\beta) = [\beta/x]\alpha$$

This says that whenever we form an expression by applying a λ-abstract to an appropriate argument, the result is equivalent to the expression abstracted over with the variable in question interpreted as denoting whatever the argument denotes. This allows us to simplify formulae.

The Translation Component. The actual natural language semantics in a PTQ-style Montague grammar resides in the translation from the natural language into the logical language. This translation proceeds in familiar fashion: there is a specification of the translations of the lexical elements, and on the basis of that the translations of complex expressions are defined. Translation presupposes a relation between the categories in the syntax of the natural languages and the types assigned to expressions of the logical language. As is to be expected category S is paired with type t. The other basic categories, IV and CN, are linked to the same type, $<s, <e,t>>$. Complex categories A/B and A\B are mapped onto types $<s, <f(B), f(A)>>$ and $<s, <f(A), f(B)>>$, respectively, where f(A) and f(B) are the types associated with categories A and B. Notice the use of the intensional types: Expressions are taken to denote senses. Thus the category T = S/IV is associated with the type $<s, <<s, <e,t>>, t>$.

Most lexical elements of category A are translated into constants of the type corresponding to A. Some, however, receive special treatment: they are translated into either logical constants or into complex expressions. A case in point are proper names. A name "John" translates, not into some constant of the appropriate type, but into the complex expression $\lambda P ^\vee P(j)$, where j is a constant of type e and P a variable of type $<s, <e,t>>$. In general, terms are taken to denote functions from worlds to sets of properties, and the proper names "John" is associated with a *specific* function of this type, viz., the function from worlds to the set of properties which the individual denoted by j has in that world. Other lexical elements that may receive special treatment, i.e., a distinct translation, that results in a distinct meaning, are modal auxiliaries, temporal expressions, and so on.

The translation of complex expressions is defined in tandem with the syntactic rules. This is necessary for two reasons: first all, such rules may introduce syncategorematic material, that needs to be interpreted; and secondly, structural properties, such as scope properties, are coded in the derivational histories. Hence, every syntactic rule, that derives a complex expression γ from a number of expressions $\alpha_1 \ldots \alpha_n$, is paired with a translation rule, that defines the translation of γ in terms of the translations of $\alpha_1 \ldots \alpha_n$. Rules which involve only concatenation are straightforward: the corresponding translation consists of functional application of the translations of the component parts. Given the strict association of categories with types this is guaranteed to result in a well-formed logical expression.

An example of a rule that introduces a syncategorematic expression is one that forms a quantified T from a CN by introducing the determiner "a". The corresponding translation rule defines the meaning of the determiner in terms of the existential quantifier as follows: $^\wedge\lambda P \exists x(^\vee\alpha(x) \wedge {}^\vee P(x))$, where α is the translation of the CN. The expression as a whole denotes the function from worlds to the set of properties P such that there is some x that has both the property expressed by the CN and P.

Another type of translation rule that deserves to be mentioned is the one corresponding to Montague's quantification rules. The latter combine a T with an S containing a special pronoun into an S, by substituting the T for the pronoun. This mechanism is introduced to account for the relative scope of two quantifiers, or of a quantifier and a modal expression. The translation rule involves abstraction over the variable x in the translation of the sentential input φ: $\lambda x\ \varphi$, resulting in an expression of type $<e,t>$, that denotes the set of objects for which φ holds. Application of the cap operator gives an $<s, <e,t>>$, i.e., an expression that denotes the property of being an object for which φ holds. The translation of the T is applied to this expression, the result being a formula again, one that expresses that the said property belongs to the set denoted by the T translation. Thus, to refer back to our initial example, if we derive "Everybody admires someone" indirectly, i.e., by means of the quantifying-in process, we first derive the sentence "Everybody admires him$_0$", with "him$_0$" a variable. The translation is a formula with a free variable, $\forall x(\text{admire}(x, x_0))$, that by λ-abstraction and application of the cap-operator is turned into: $^\wedge\lambda x_0\ \forall x(\text{admire}(x, x_0))$, which denotes the property of being admired by everyone. From the translation of the T "someone" we get: $\lambda P \exists x\ {}^\vee P(x)$, which denotes the set of properties someone has, and the translation of the entire construction is functional application of these two expressions: $\lambda P \exists x {}^\vee P(x)\ (^\wedge\lambda x_0\ \forall x(\text{admire}(x, x_0)))$. This says that the property of being admired by everyone is a property that someone has, which is the intended reading. The formula in question can be simplified by performing λ-conversion (twice) and taking alphabetic variants, resulting in the more familiar, first-order representation $\exists y \forall x(\text{admire}(x, y))$. In a similar fashion de dicto and de re readings of sentences with intensional verbs and quantified objects are derived.

One element that strictly speaking does not belong to the translation component, but that *is* involved in getting the semantics of the natural language right, is Montague's use of so-called 'meaning postulates'. These meaning postulates are formulae of the logical language that serve as restrictions on the models that are taken into consideration as proper models for the natural language expressions. Only such models as make these formulae valid are to be taken into account. The meaning postulates express a variety of semantic properties of expressions, or classes of such. For example, the synonymy of two lexical expressions is not accounted if they are translated into non-logical constants, since the interpretation function of a model only says something about the semantic type, not about the actual semantic object that is the interpretation of such constants. By adding a meaning postulate that expresses that the respective constants are co-extensional in all worlds, we effectively limit ourselves to models in which the two lexical expressions are interpreted as synonymous. Other postulates concern properties of classes of expressions, such as the intersectivity of certain adjectives. Used in this way, meaning postulates permit us to blur the sharp distinction between logical and non-logical constants that is inherent in most logical formalisms.

Core Principles. From this sketch of the main ingredients of Montague's original PTQ-model, we can derive the following general features, which are characteristic of the enterprise of Montague grammar in general:

A. Semantics is syntax-driven, syntax is semantically motivated
B. Semantics is modeltheoretic

The first characteristic is, of course, closely related to the principle of compositionality. It comes to the fore at several points, among which the correspondence between syntactic categories and semantic types, and the grounding of structural ambiguities in syntactic derivations are the most prominent. It clearly demonstrates that compositionality constrains both syntax and semantics. Any semantic object or operation on such objects has to have a correlate in the syntax, an expression or operation that triggers it. And conversely, all expressions and all structural operations in the syntax have to have a semantic correlate. Thus the autonomy of syntax is limited. That categories are mapped onto semantic types illustrates this. In so far as the categorial labeling of the expressions in a string is akin to more familiar constituent structure, it implies that all of constituent structure is semantically interpretable. And the requirement that any syntactic rule has to be matched by a corresponding translation rule, in effect, says that there can be no syntactic operations which are not somehow interpretable in terms of operations on semantic objects.

The strong coupling of syntax and semantics implies that for every semantic phenomenon there has to be an analogue in the syntax. The way in which scope is handled is, of course, a perfect illustration. There is no independent syntactic motivation for something like Montague's quantifying in rules: they are part of the syntax simply and solely for semantic reasons.

In order to implement compositionality in this particular way, the use of a logical representation language with a type structure and the means to form new complex expressions by means of λ-abstraction is imperative. Only with such expressive means at our disposal can compositionality be implemented as strictly as is done in Montague grammar.

An interesting question is whether this strong form of compositionality actually can be empirically motivated, or whether it is an empirical hypothesis in the first place. It seems that without *independently* motivated constraints on either syntax or semantics, the latter question has to be answered in the negative. If there are no such constraints, we can always set up things in such a way that compositionality is met. In that sense it is not so much an empirical hypothesis as well as a methodological principle. However, once we impose certain restrictions on either the organization of the syntax or on that of the semantics, it may very well be that the compositionality requirement can not be met.

The second characteristic, that semantics is modeltheoretic, places Montague grammar squarely in the dominant logical tradition. As far as meaning is concerned, it seems, entailment relations between (classes of) expressions are the primary data of semantics. It is in terms of entailment that all the important semantic properties of an expression can be explained, including ambiguity, synonymy, special properties such as factivity, and so on. These data, acquired by means of introspection, are accounted for by associating the expressions involved with the proper semantic objects, viz., those that have corresponding relations among themselves. Consequently, models are constructed, in principle, solely on the basis of what is needed for an account of the data, no other constraints, of a philosophical nature for example, are accepted. However, this does not mean that the ontology of the models is completely fixed by the semantic facts: there is, in most cases, more than one type of model that fits the data. This explains, to some extent at least, that in some cases more or less the same range of semantic phenomena is accounted for in the literature in a number of divergent ways. Especially those aspects of natural language semantics which involve expressions and concepts that are loaded with philosophical implications and presuppositions, display this. A case in point is the semantics of attitude verbs, such as *believe* and *know*, or that of the temporal and aspectual system. The analysis of plurality, too, is rife with philosophical and logical controversies.

An immediate correlate of the modeltheoretic perspective on meaning is that there is a strict division between semantics and pragmatics. Semantics deals with meaning, i.e., with modeltheoretic interpretation, and pragmatics deals with use. Meaning and use are hierarchically related in this sense that meaning is supposed to be independent of use, but not vice versa. Hence, semantics can proceed without pragmatics, but the converse does not hold. Since pragmatics is about how we use the expressions of our language given the meaning they have, pragmatics presupposes semantics.

Here Montague grammar abides with what for a very long time was accepted wisdom, viz., the Gricean division of labor between semantics and pragmatics. Despite early dissidents, such as Stalnaker (Stalnaker 1979), the idea that the tasks and domains of semantics and pragmatics can be strictly separated, was dominant until well into the 1990s, certainly among semanticists of a modeltheoretic inclination. It was only due to a change in semantics itself that this picture began to change as well.

Concomitant with the second characteristic is a feature that Montague grammar shares with almost all linguistic frameworks up until quite recently, viz., an exclusive focus on the sentence as the primary unit of analysis: grammar is sentence grammar. That was the case in the Chomskyan framework, and in almost all of its offshoots and alternatives, and Montague grammar is no exception. It actually inherits this feature from both its ideological sources. The first of these is the Chomskyan tradition, that Montague himself considered as an ally in the fight against the then still prevailing opinion among philosophers and logicians that natural language is too vague and unsystematic to lend itself to formal treatment. (Of course, for the reasons sketched above, Montague adopted a different outlook on syntax than Chomsky did.) And secondly there is the logical tradition itself, which throughout its long tradition has focused on relations between judgments, propositions, statements, or whatever they were called, but all "sentence like" objects.

4. Applications and developments

Montague grammar, in particular the PTQ-model, was the dominant paradigm for formal semantics of natural language during the 1970s and much of the 1980s. To review the various ways in which it has been applied is beyond the scope of this article. We will have to confine ourselves to a brief indication of some remarkable specimens. For more details, and an extensive bibliography, the reader is referred to the survey in Partee/Hendriks (1997).

It may be useful to distinguish between applications, extensions, and amendments of Montague's original model. Applications of the PTQ-model stay, more or less, within the confines of Montague's formulation and extend its range of application by analyzing new phenomena, using the tools already at hand. Extensions broaden the scope of the theory, not just by bringing it to bear on new phenomena, but also by extending its theoretical apparatus, i.e., by introducing new concepts and techniques. Amendments actually change the model in some way, by replacing certain tools or techniques by different, more adequate ones. An amendment may be triggered by both empirical or conceptual shortcomings. Of course, in reality most contributions to the field are mixtures.

The early years were devoted mainly to applications of the PTQ-model, on a variety of empirical data, such as tense and aspect (Dowty 1979), plurals (Bartsch 1973), mass nouns (Bennett 1979), lexical meaning (Dowty 1976), adverbs and adjectives (Siegel 1976), control verbs (Bach 1979), and so on. Most of these analyses stayed fairly close to Montague's original formulations, but brought out its descriptive and explanatory potential by incorporating more empirical phenomena.

Extensions of Montague grammar were often triggered by a felt need to use different semantic concepts than were available in the original formulation. A good example is the analysis of tense and aspect. In due time it became clear that the original tense logic incorporated in Montague's intensional type theory was rather limited. Other options were explored, such as analyses in terms of events and their properties (Hinrichs 1986), or analyses that used intervals (Dowty 1982). Another example of an extension of this kind involves the use of a strictly typed logical system, another feature of Montague's model. Every expression here can be assigned to only one type, fixing both its logical syntax and its semantics. Thus, for example, properties and objects are strictly separated. In the analysis of nominalizations this was felt as a shortcoming, and some proposed to (partly) replace Montague's typed system with a form of property theory (Chierchia & Turner 1988). Yet another example concerns the analysis of plurality and quantification involving plurals. Montague's set-theoretic, individual based semantics was found lacking, descriptively and explanatorily, and other analyses were proposed in terms of algebraic structure (Link 1983) and plural objects (Landman 1989).

All these developments extended Montague grammar by replacing some elements of the semantic theory by different ones, thus increasing its descriptive and explanatory range. Another type of extension is exemplified by work that explores the original model in new directions. One of the most successful examples of this type of development is provided by generalized quantifier theory. Montague's original analysis of terms, i.e., noun phrases, treats them, extensionally speaking, as sets of sets. (And determiners, as a distinct syntactic category, are analyzed as relations between sets.) Such sets of sets are generalized quantifiers, and by exploring their underlying logic, a whole new branch of semantics grew out of Montague's proposals. Initiated by Barwise and Cooper (1981), van Benthem (1983), and explored by many others, this turned out to be a very fruitful area of investigation, with ramifications far beyond the original analysis of terms. Another area explored in this way is the analysis of non-indicative sentences, such as interrogatives (Karttunen 1977, Groenendijk & Stokhof 1982). The fact that Montague's model can be extended to apply also to interrogatives, shows that the idea that modeltheoretic semantics is biased towards, or even restricted to, declarative language is a misconception.

Important amendments of Montague's original model are connected with his analysis of structural ambiguities involving quantified expressions, intensional verbs, and so on. As we saw above, Montague postulated additional syntactic rules in order to provide a derivational basis for such ambiguities. For various reasons, a number of authors were dissatisfied with this approach and developed alternative ways of dealing with these semantic facts. Cooper provided one such an alternative, using so-called "storing" of quantifiers and variables (Cooper 1979). Another approach was pioneered by Partee (Partee 1987) and worked out in detail by Hendriks (Hendriks 1993). It involves so-called "flexible type assignment" and does away with Montague's strict correlation of syntactic categories and semantic types by using a calculus of so-called 'type-shifting rules' that allow expressions to be analyzed in different types and with different scope relations.

The upshot of the various extensions and amendments was that certain basic aspects of Montague's original model were gradually beginning to change as well. For example, compositionality becomes an issue that has to be re-thought once the strict category-type association is loosened (see Janssen 1997 for an extensive overview). And another effect of the proliferation of extensions and changes of the original semantic apparatus was that the original unity of the various analyses carried out within the framework was lost. "Montague grammar" became a way of doing semantics, still modeltheoretic semantics, but using different logical theories for different domains. In this sense the very character of the enterprise of Montague grammar changed.

5. Beyond Montague grammar

There are a number of reasons why formal semantics eventually abandoned some basic tenets of the Montagovian framework. We will briefly sketch two of them, each concerned with one of the core principles that were identified in section 3.

The syntax-semantics interface. Montague's use of categorial syntax was motivated mainly from a semantic point of view. In particular, it was the category − type agreement that made categorial grammar something of a natural choice. As we saw, for Montague syntax was not autonomous in this sense that he did not hesitate to add rules to the syntax just to get the semantics right, without any independent syntactic motivation. Furthermore, the kind of categorial syntax Montague used, provided a rather poor descriptive framework.

From a linguistic point of view these were definite weaknesses in Montague's original model, and over the years a lot of work has been done to overcome this. Several people have combined a semantics in Montague's style with different syntactic frameworks. There were some early attempts to combine a Montague semantics with a classical transformational grammar (Partee 1976). Later efforts were concerned with syntactic theories which were closer to the original ideas of categorial syntax, but were motivated by considerations internal to syntactic theory. Here work on unification grammar (Shieber 1986) needs to be mentioned as well as modifications that use generalized phrase structure grammar (Gazdar, Klein et al. 1985) and head driven phrase structure grammar (Pollard & Sag 1994), as well as lexical-functional grammar (Kaplan & Bresnan 1982). Somewhat separately, categorial grammar itself was explored and expanded in various directions (Moortgat 1988, Steedman 1993).

Many of the developments in this area have also received an impetus from the use of derivatives of Montague grammar in computational linguistics. Since Montague grammar was the first grammar model that featured a formal semantics, it was a natural choice for those tasks in computational linguistics which required semantics, or some kind of understanding on part of the users of a system, such as translation and dialogue modeling. In these contexts extensive descriptive coverage is a necessary feature of the model, something that Montague's original syntax did not supply, hence the use of different syntactic frameworks.

With the incorporation of internally motivated syntactic theories, Montague's original conception of the syntax−semantics interface was modified. First, other ways of satisfying compositionality were explored that did not rely on syntactically unmotivated rules in the syntax to get the semantics right. Here such techniques as mentioned above, Cooper stores and flexible type assignment, were used to loosen the demands placed on syntax by semantics. Later on the outlook on the syntax–semantics interface itself changed, and syntax regained a more autonomous status.

Modeltheoretic semantics. An important development in the 1980s and 1990s was the move away from the traditional sentence grammar to systems which are able to deal with larger units of discourse, such as texts and dialogue, a move that also involved radical changes of the Montague grammar framework.

An external impetus came from natural language research within artificial intelligence, where interpretation is viewed as the execution of procedures which change the state of a system as it proceeds. Another influence came from computational linguistics, that had to deal with larger units than sentences in actual implementations. And there was an internal stimulus, that concerned certain persistent empirical problems that could not be solved in a sentence oriented formalism such as Montague grammar. A simple but illustrative example is provided by cross-sentential anaphora. In a discourse such as "A woman walked into the room. She was wearing a black velvet hat.", the pronoun "she" is naturally interpreted as bound by the indefinite noun phrase "a woman". If interpretation proceeds on a sentence by sentence basis, this can not be accounted for, since the antecedent is processed before the anaphor is encountered. And delayed interpretation, i.e., linking antecedent and anaphor only when the discourse is finished, makes wrong predictions in other cases, such as "The restaurant was empty except for one man, who was sitting by the window. He was wearing blue suede shoes."

It was phenomena such as these that led to a view on interpretation as a dynamic process, one that proceeds incrementally as a discource or text unfolds. In the beginning of the eighties such a dynamic view was formulated explicitly in Discourse Representation Theory (DRT; Kamp 1981, Kamp & Reyle 1993) and File Change Semantics (Heim 1983). DRT is a dynamic theory of interpretation, locates the dynamics in the process of building representational structures. These structures are initiated by incoming utterances and added to, or modified by, subsequent utterances. The structures themselves are interpreted in a static way by evaluating them with respect to a suitable model. Dynamic semantics (Groenendijk & Stokhof 1991, Groenendijk, Stokhof & Veltman 1996) takes the idea of dynamic interpretation one step further and locates the dynamics in the concept of meaning itself. The basic starting point of dynamic semantics can be formulated in a slogan: "Meaning is context-change potential". Unlike DRT dynamic semantics does not rely on representations, but assigns expressions a dynamic meaning in a compositional way.

The development of these dynamic theories also paved the way for a major reorientation of the relationship between semantics and pragmatics. More and more aspects of language use, such as embodies in Grice's original theory of conversational maxims (Grice 1975), or in theories of presupposition, are incorporated into semantics. Meaning no longer is identified with Fregean sense (and reference), but rather with the way in which utterances, i.e., uses of sentences in contexts, change that very context. And the context includes information states of language users, about the world and about themselves and each other, their intentions and expectations, and so on. These developments have given rise to new perspectives such as the use of game theory in the analysis of language, in which the borderline between semantics and pragmatics is drawn in quite different ways, if at all (Dekker & van Rooy 2000).

Finally, another way in which Montague's original proposals are being changed and transformed is connected with the increasing interest in the cognitive reality of linguistic modeling. Montague stood in a tradition that was shaped by Frege's antipsychologism in logic. And his grammar model bore witness to that: meaning is analyzed in a purely formal way, that does not refer to any cognitive embedding or realization of the concepts and principles used. The increasing interest in the way in which meaning and use interact, that is characteristic for the developments in the late 1990s and that is still continuing, is changing this, too, and is bringing, if not Montague grammar itself, then at least his successors closer to cognitive research on language and meaning.

For that, despite all the changes, there is still a living tradition in semantics that owes a great debt to Montague's work, is evident from the high standards of rigor and exactness that were once revolutionary, but are now accepted as defining characteristics of what this field of inquiry is all about.

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222. Le développement des grammaires casuelles au XXe siècle

1. Le paradoxe casuel

Le cas en grammaire est une catégorie paradoxale et ambivalente. Paradoxale parce que régie par le verbe mais marquée sur le nom et supposée comme universelle en tant que catégorie régie, mais exprimée par zéro ou au contraire par une pléthore de formes dans les langues. Ambivalente parce qu'à la fois syntaxique − les cas grammaticaux exprimant voix et valence − et sémantique, les cas concrets exprimant les coordonnées spatio-temporelles et adverbiales de l'énoncé. En outre, ses inventaires et son expression, qui concernent la morphologie, sont à la fois distribués dans les paradigmes lexicaux (noms et pronoms) et fonctionnels (les déterminants, les adjectifs), et contraints par le filtre phonologique, responsable de phénomènes de distribution complémentaire et de syncrétisme.

La théorie du cas se trouve tiraillée entre toutes les composantes de la langue: sémantique, syntaxe, morphologie, phonologie. La tentation est donc grande d'en faire un observatoire privilégié en faveur de théories plus