16

Logic and Linguistics in the Twentieth Century

Alessandro Lenci and Gabriel Sandu

1. Introduction

A crucial aspect of the revolution that affected logic at the beginning of the twentieth century concerns the severance of its traditional dependence on the form and structure of natural language. Such a breakdown has had enormous consequences not only for the development of formal logic but also for the opening of new perspectives in the study of language. This peculiar relationship between mathematical logic and language inquiry is best illustrated by Willard V. O. Quine (1961, 1):

> Mathematicians expedite their special business by deviating from ordinary language. Each such departure is prompted by specific considerations of utility for the mathematical venture afoot. Such reforms may be expected to reflect light on the ordinary language from which they depart.

As a major consequence of its "reforms," the new mathematical logic has been able to revivify and boost the notion of *philosophical* and *logical grammar*, typical of the seventeenth- and eighteenth-century rationalist tradition. New life has therefore been given to the idea that there exists a common grammatical core shared by every language and determinable a priori, with respect to which diversity and variation are just prima facie features of natural language, hiding its universal logical structure.

The dominant and almost exclusive role of logic in the quest for the universal principles of human language has however been radically challenged in the course of the century by the arising and fast growth of *generative* linguistics, which has claimed the investigation of universal grammar as the major goal of linguistic science. In contrast with the descriptive and empiricist approach of structural linguistics—mostly focused on the taxonomic study of particular languages—Noam Chomsky has reaffirmed the need for a rationalist perspective on language analysis. The focus on the formal properties of language structure, the central role occupied by the study of syntax and of language creativity, the attention to the relation between syntactic composition and meaning, the inquiry into the universal principles that form the conditions of the possibility of human language have thus become the core areas of research in generative theoretical linguistics, thereby granting an important convergence with the research and the aims pursued in the field of logical grammar.

The Chomskian revolution has therefore deeply affected the relationship between logic and linguistics, the latter being intended as a naturalistic scientific enterprise subject to the same methodological requirements of other *Naturwissenschaften* like physics or chemistry. On one hand, the rationalist turn in linguistics has actually allowed for an unprecedented convergence of linguistics with important areas of mathematical logic. On the other hand, the generative paradigm has also set constraints on the study of natural language and formulated hypotheses on its architecture that have often dramatically conflicted with the logicomathematical approach. Thus, the history of the relationship between logic and theoretical linguistics in the past decades is rather a deeply dialectic one. It is a history of profound and synergic efforts toward the common aim of understanding the nature and universal principles of human language and its formal structure, but it is also an history of harsh conflicts and divergences on the nature of universal grammar itself. At the core of this confrontation lies the issue of the relationship between grammatical form and logical form, that is to say, the possibility itself of carving out the natural language syntactic and semantic space as a logical space. This is also primarily related to the role of meaning in the architecture of language, that is, its methodological function in guiding the discovery of language universals, the proper nature of a semantic theory, and the relationship between syntactic descriptions and semantic interpretation. Such questions have reached their peak with the debate on the *principle of the autonomy of syntax*, which was proposed by Chomsky since the very outset of the generative enterprise, and has largely dominated and oriented the discussion throughout this period.

Logic and generative linguistics have partly been divided by the inherently cognitive and psychological orientation of the rationalist approach boosted by Chomsky. While mathematical logic has mostly focused on a mind-independent, speaker-independent notion of language, generative linguistics is, in fact, ultimately interested in the principles of language intended as the description of a particular cognitive faculty of speakers. Moreover, the tradition of logical grammar—with the major landmark of Richard Montague's contribution—is largely dominated by the hypothesis that actually no substantial difference exists between natural language and formal languages (Montague 1974). Differently, the major constraint imposed by Chomsky on the principles of universal grammar is rather an empirical one, that is, whether they provide a real explanation of speakers' knowledge of language and of men's innate capability to acquire language. Therefore, the history of the interactions between these disciplines is also deeply related to a fully theoretical issue, namely, how much is language amenable to a treatment as a formal language. In this way, reconstructing the difficult and contrasted history of the interactions between logic and contemporary linguistics leads us to set and investigate crucial philosophical questions concerning the nature of language and the way to face its complexity.

The interaction between logic and linguistics on the nature of universal grammar can be roughly divided into three phases, which will be analyzed in details in the next sections. The first phase (beginning of the century up to the 1960s) was characterized by an extremely intense work in the field of logical grammar (section 2), with the rising of categorial grammar within the Polish School in the first decades of the century and its extensive application to ordinary language by Yehoshua Bar-Hillel in the early 1950s. Besides, the work on truth-conditional semantics by Tarski, Quine, and Davidson (section 3) provided the necessary background to the model-theoretic analyses of natural language and to Montague grammar in the 1970s. On the linguistics side, in 1957 the transformational generative paradigm made its first steps out of the banks of American post-Bloomfieldian structuralism and behaviorism (section 4). Chomsky's critique of the inadequacies of phrase structure grammars had a strong impact on the tradition of logical grammar, by revealing the limits and problems of categorial models. Moreover, in these years the generative architecture of the universal grammar received its first shaping, accompanied by the initial steps of the debate on the role and nature of semantic theory.

The second phase (the late 1960s, throughout the 1970s) began with the crisis of the semantic models developed in the early period of generative grammar and the rise and fall of the generative semantics enterprise (section 5). One of the major events of this period was the explosion of Montague grammar and the subsequent breakthrough made in the linguistic community by the development of model-theoretic semantics (section 6). More generally, these years were characterized by a great debate on the proper position of semantics within the theory of grammar, and by the first attempts to carry out extensive comparisons and integrations between generative linguistics and logical grammar.

The third phase (starting from the beginning of the 1980s) is best illustrated by referring to the central role acquired in the Government and Binding version of Chomsky's theory by the notion of logical form (LF) (section 7), resulting in an intense work in linguistics on topics like quantification, coreference, and so on, with the consequent constant readjustment of the border between logic and formal linguistics.

Before starting, let us make a final general remark. Talking about logic and linguistics in the twentieth century unavoidably entails presenting theories and models which often not only belong to the history of these disciplines but also form the daily working tools for militant researchers and scholars. This is exactly what happens with Montague grammar and generative linguistics. Therefore, the following sections are not intended to represent general introductions or descriptions of any of these frameworks, for which very good manuals and summarizations exist at various degrees of difficulty and for various audiences. The discussion will rather be focused on trying to reconstruct the dynamics and interactions between these approaches in logic and in linguistic theory, which represent the major landmarks in the quest for the individuation of the universal structure of language.

2. Logical Grammar

2.1. Frege and Russell

For Frege, the most important concept of logic is truth. It is the analysis of this notion that forced him to create a theoretical framework in which sentences are broken into parts which in turn are related to entities in the universe in a systematic way. By taking truth as the focal point of his considerations, Frege was the initiator of a semantic project that was to dominate the logical study of language up to the present day. Even if semantics proper was established as a discipline much later by Tarski (who also introduced the Polish analog of the name in 1936), Frege saw probably more clearly than any other how an analysis of the truth of a sentence compels one to introduce meaning (referential) relations between expressions of the sentence and extralinguistic entities. Frege's views about the logical analysis of language constituted a complete break with the tradition. Before him it was customary to write things like this:

> Every categorial proposition has a subject, a predicate, a copula, a quality and a quantity. Subject and predicate are called "terms." For example, in "the pious man is happy," "the pious man" and "happy" are terms of which "the pious man" is the subject, "happy" is the predicate, and "is" is the copula. The "quality" of the proposition is affirmation or negation ... the "quantity" of a proposition is its universality or particularity. (Leibniz, *Opuscules et fragments inedits de Leibniz*, 77–78)

Nothing could be further from Frege. He rejected explicitly the distinction between subject and predicate (something that will find an echo later on in Chomsky's redefinition of grammatical subject; see section 4.2):

> A distinction between *subject* and *predicate* finds *no place* in my representation of a judgment. Now all those features of language that results only from the interaction of the speaker and listener ... have no counterpart in my formula language, since here the only thing that is relevant in a judgement is that which influences

> its possible consequences. [In this I closely follow the formula language of mathematics, in which subject and predicate can also be distinguished only by violating it]. (Frege 1879, §3)

Instead, he introduced (Frege 1891) the distinction much more familiar to him from his training as a mathematician between *object* and *function*. According to it, the sentence "John is tall" is to be analyzed into a concept word "tall" and the proper name "John." The latter designates an object, the bearer of the proper name. The former designates a concept, that is, a function that for Frege is an unsaturated entity whose arguments are objects and whose values are the truth values *True* or *False*. Thus in our example, the concept-word "tall" designates the concept which, for every object as its argument yields the truth value *True* if and only if that object is tall; the whole sentence designates *True* if and only if the individual designated by "John" is tall.

The rejection of the subject-predicate distinction can be seen even more clearly in the case of relational expressions. The statement "3 is greater than 2" ("$3 > 2$") is not to be analyzed into the subject "3" and the predicate "is greater than 2" but into the relation symbol "is greater than" and the proper names "2" and "3" (Frege 1891, 154).

Frege's analysis of quantifiers ("signs of generality") constituted another break with the tradition. His predecessors regarded the sentences

(∗) "Socrates is mortal"

and

(∗∗) "Everyone is mortal"

as having the same logical complexity, that is to say, (∗) was regarded as equivalent to "Every Socrates is mortal," where "Socrates" is a term denoting one single object. Frege saw things in a completely different way. (∗) is for him an atomic sentence built up from the proper name "Socrates" and the concept-word "mortal," while (∗∗) is a statement of generality in which the (first-level) concept designated by "mortal" is the argument of the (second-level) concept designated by the sign of generality "everyone."

> It must be here remarked that the words "all," "any," "no," "some," are prefixed to concept-words. In universal and particular affirmative and negative sentences, we are expressing relations between concepts; we use these words to indicate the special kind of relations. They are thus, logically speaking, not to be more closely associated with the concept-words that follow them, but are to be related to the sentence as a whole. (Frege 1892, 187)

In Frege's perspicuous notation, introduced in his *Begriffsschrift*, the position and role of every expression as well as their level are clearly specified. Thus the general form of statements of generality like (∗∗) is

$$\underbrace{\;a\;}\ f(a),$$

where "f" indicates the place of the first-level function which is its argument (Frege 1891, 153). The second-level concept designated by "every" is defined as the function that takes the value *True* for a first-level concept as its argument (to be inserted in the position indicated by "f") if and only if the first-level concept takes the value *True* for every object in the universe; otherwise it has the value *False*.

It is worth emphasizing that Frege's views on logic together with the conceptual notation that went along with it opened the door for possibilities undreamt of by his predecessors, which found their place into both logic and linguistics once and for all. Let us focus on those which are relevant for the present study.

First, we have in Frege for the first time the idea of the derivational history of a sentence with the engendered possibility of determining its truth or falsity in stages, beginning with the atomic stage. Frege's procedure is not entirely compositional with respect to *truth*, that is, the truth of a compound sentence cannot be obtained from the truth of the *compounds*, and this for the simple reason that the compounds are not always sentences. Since for Frege variables are empty places which indicate the positions where arguments must be filled in, and not terms receiving meaning through an assignment, he could not and did not have the notion of satisfaction available, which had to wait for Tarski's work. But he still could define, and in fact he did, as Dummett has observed, the *truth* of a compound sentence *in stages*. Thus the sentence "everyone is mortal" is *True* if and only if "George is mortal" and "John is mortal," and so on, that is, if and only if the first-level concept word "mortal" yields the value *True* when we run through all the (names of) objects in the universe which are persons.

Second, Frege's categorical distinction between objects and concepts, and the syntactical distinction between complete and incomplete expressions that goes along with it gave rise to a hierarchy of levels which, in turn, yields a theory of signification for natural language sentences. In other words, he was able to explain why certain sentences in natural language, although grammatical, are completely meaningless or paradoxical. As Dummett pointed out, the failure of significance of such sentences is accounted for by the impossibility of constructing a corresponding sentence in the symbolic language. We find essentially the same idea later on in Russell's theory of types as well as in the categorical languages of the Polish school (Ajdukiewicz and Lesniewski) which grew out of Husserl's work. The explanation goes shortly like this.

At the basis (level 0) of Frege's hierarchy of levels, we have complete names, that is, proper names and sentences, while all the expressions situated at higher levels are incomplete. Thus at the first level we have one-place predicate expressions of first-level which are incomplete expressions obtained from sentences by removing one or more occurrences of a proper name. Frege used the notation

$$\ldots \xi \ldots$$

to denote a first-level one-place predicate which has been formed from a sentence

$$\dots\ a\ \dots$$

by removing one or more occurrence of some proper name “a” and leaving a gap indicated by the Greek letter ξ to mark the argument place of the predicate. On the same level we also have two-place, three-place, and so on relational expressions of first-level and also one-place, two-place, and so on functional expressions of first-level, that is, incomplete expressions obtained from proper names by removing one or more occurrences of other proper names.

At the next level we find second-level predicates, that is, incomplete expressions obtained from sentences by removing one or more occurrences of first-level predicates. Typical examples are quantifiers, like our earlier example “$\underbrace{\;a\;}\, f(a)$,” where “$f$” shows the gap left by the removal of the first-level predicate, and the expressions “a” in brackets shows the initial argument of the removed first-level predicate.

Suppose now that we want to insert a new first-level predicate in the argument place of the second-level relation. We will have to put that predicate in the place of f and then insert a as its argument. This mechanism shows why we cannot insert a proper name in the argument place of a second-level predicate: There is no place for the argument left by the removal of the first-level predicate to go to. For similar reasons, we do not obtain a sentence when we insert a first-level predicate into the argument place of another first-level predicate, for the resulting expression still contains a gap ξ to be filled in.

We are now able to understand what is paradoxical about natural language sentences like “The concept horse is not a concept” if interpreted as saying something about a concept or, to borrow an example from Dummett, why certain natural language sentences like “Chairman Mao is rare” are perfectly grammatical, yet meaningless. The reason is that “is not a concept” denotes a second-level concept although it appears in the grammar of English as a first-level one. And the same goes for “is rare” in the second example. In other words, what in the grammar of natural language appears like a first-level predicate, is not so in logic:

> The concept of a function must be a second-level concept, whereas in language it always appears as a first-level concept. While I am writing this, I am well aware of having again expressed myself imprecisely. Sometimes this is just unavoidable. All that matters is that we know we are doing it, and how it happens. In a conceptual notation, we can introduce a precise expression for what we mean when we call something a function (of the first level with one argument). (Frege, letter to Russell, 1902)

Dummett has drawn attention to the fact that Frege’s hierarchy of levels is essentially the same as Russell’s theory of simple types formulated in terms of Frege’s notion of incomplete expressions. Although Russell does not explicitly make the distinction between complete and incomplete expressions, we find in his notion of "ambiguity" essentially the same notion of incomplete expression and the same criteria of significance as in Frege:

> Thus "$(x).\varphi x$," which we have already considered, is a function of φx; as soon as φx is assigned, we have a definite proposition, wholly free from ambiguity. But it is obvious that we cannot substitute for the function something which is not a function: "$(x).\varphi x$" means "φx in all cases," and depends for its significance upon the fact that there are "cases" of φx, i.e., upon the ambiguity, which is characteristic of a function. This instance illustrates the fact that, when a function can occur significantly as argument, something which is not a function cannot occur significantly as argument. But conversely, when something which is not a function can occur significantly as argument, a function cannot occur significantly. (Whitehead and Russell, *Principia Mathematica*, 48).

Later on we shall regain Frege's hierarchy of levels in the Lesniewski–Ajdukiewicz grammar of semantic categories. As we said at the beginning of this section, truth was for Frege the main concept of logic, and truth is a property of sentences and thoughts. Thoughts and sentences were thus primary for Frege, but this did not prevent him to realize the combinatorial and compositional power of language, a methodological credo that was to remain constantly transparent in his writings and after him was going to mark, if not even demarcate (see section 4.1), the project of logical grammar of the Polish school, Carnap, Davidson, and Montague from other developments in the study of language. Indeed, Frege wrote:

> It is astonishing what language can do. With a few syllables it can express am incalculable number of thoughts, so that even if a thought has been grasped by an inhabitant of the Earth for the very first time, a form of words can be found in which it will be understood by someone else to whom it is entirely new. (Frege 1923–1926, 390)

2.2. Husserl's Theory of Meaning Categories

Husserl was directly concerned with the question of what makes natural language expressions significant. The answer he gave to this question is essentially the same as that given by Frege before him: in virtue of these expressions obeying the principles of combination and substitution governing the meaning categories they belong to. Thus like Frege, Husserl makes categorical distinctions and states explicitly the connections between expressions belonging to different categories. These connections are codified in the so-called *meaning connection rules*, which state the mode of combination and substitution of different expressions into more complex ones. These rules allow Husserl to explain why combinations of certain strings in language are nonsensical. The purely *logical grammar* is the set of a priori laws common to all languages.

To understand Husserl's meaning connection rules, we have first to understand his distinction between *form* and *matter*, that is, between expressions signifying forms and expressions signifying matters. In the sentence

(1) This house is green.

the words *this* and *is* do not have an independent meaning: They are *syncategorematic* expressions, that is, expressions that become meaningful only after completion with other expressions. For Husserl, *syncategorematic* expressions signify *forms*, in contradistinction to nominal expressions, like *house* and adjectival expressions like *green* which signify *matters*, that is, things and entities in the world, and so on. He perspicuously observed that in (1) we can substitute nominal matters for *house* and adjectival matters for *green* and the result is an expression which is still "well formed," or, in Husserl's words, it has a unitary meaning. So in (1) we can discern an underlying propositional form

(2) This S is p

which yields unitary meaning only if substitute for the variables S and p expressions belonging to the same *Bedeutungskategorien* (*meaning category*, as distinguished from the term *semantic category* used later by the Polish school). (See also Casadio 1988.)

Each such form has associated with it a *meaning connection rule* which states to which meaning categories the expressions substitutable for the variables of the form must belong. In Husserl's words:

> each primitive form adheres to a certain a priori ... law stating that every meaning connection obeying that form effectively gives rise to a unitary meaning, provided that the terms (the underdetermined elements, the variables of the form) belong to certain meaning categories. (Husserl 1913, 330)

In the case of (2), the meaning connection law states that any nominal matter may be substituted for S and any adjectival matter may be substituted for p.

If in a form we violate the meaning connection rule by substituting for the variables in the form words belonging to inappropriate categories, the resulting expression turns out to be nonsignificant or *nonsense* (Unsinn). This happens, for instance, if in (2) we substitute for S an adjective like *careless* and for p an adjective like *green* (which is appropriate). However, even if we obey the meaning connection rules, we may get an absurd expression like

(3) This quadrilateral has 5 vertices.

which does not denote a possible state of affairs (Husserl 1913, 327). This is a case of *countersense* (Widersinn). The distinction between nonsense and countersense justifies Husserl to introduce two kinds of laws: laws of avoiding nonsense and laws of avoiding formal countersense (Husserl 1913, 334–335). We see that for Husserl, nonsense is prevented by the meaning-connection rules.

Bar-Hillel has made the interesting observation that Husserl's distinction between nonsense and countersense is an anticipation of Carnap's distinction between *formation rules* and *transformation rules* (Bar-Hillel 1970, 93; Casadio 1988, 116). In Carnap's *Logical Syntax of Language* (1937), the former define the well-formed expressions (sentences) of a language, and the latter define the set of sentences that are consequences of a system of axioms. In this setting, the sentence (3) cannot be true, whereas the sentence *This careless is green* is not a sentence at all. According to Bar-Hillel, Husserl's insight that the rules of avoiding nonsense are logically prior to the rules of avoiding countersense is nothing else that the Carnapian requirement that the statement of the rules of formation has to precede its rules of transformation (Bar-Hillel 1970, 93–94).

The Husserlian distinction between form and matter reminds one of the Fregean distinction between complete and incomplete expressions and the ontological distinction between objects and concepts which goes along with it. Some of the incomplete expressions became later in the Polish school the *functorial* (*operator*) categories.

2.3. The Polish School

The Polish school gathered philosophers and logicians who worked in Lwow, Warsaw, and Krakow between the two wars. However, the history of the group starts much earlier with Twardowski, who attended Brentano's lectures. Twardowski taught in Lwow and so did his pupil, Lukasiewicz. Among the students of the latter one could find Leśniewski, Ajdukiewicz, and Kotarbinski. Leśniewski and Kotarbinski moved later to Warsaw where a new generation of logicians was raised, including Lindebaum, Sobocinski, and Tarski.

One of the main problems considered by many of the logicians in this group was to give an adequate answer to the question raised by Husserl, namely, "the specification of the condition under which a word pattern, constituted of meaningful words, forms an expression which itself has a unified meaning. . . . A word pattern of this kind is syntactically connected" (Ajdukiewicz 1935, 1). We pointed out earlier that Frege's categorical distinctions and Russell's theory of types were intended as an answer to the same question. However, for reasons we cannot go into here, Russell's theory of types was found dissatisfactory, and many logicians in the group adopted instead the theory of semantic categories expounded by Leśniewski in *Grundzüge eines neuen Systems der Grundlagen der Matematik* (1929). Leśniewski made a distinction between language and metalanguage, which was later explored by Tarski. He was also the first to point out that every language which contains its own semantics cannot obey the laws of classical logic, and if those laws are to be preserved, one has to reconstruct the language through hierarchical levels, where each level is interpreted in the next one.

2.4. Leśniewski and Ajdukiewicz: The Grammar of Semantic Categories

Leśniewski's theory of semantic categories, which he formulated around 1922, was deeply influenced by Husserl's theory of meaning categories and by Russell and Whitehead's theory of types. For Leśniewski, too, any expression, understood as a finite sequence of inscriptions, belongs exactly to one semantic category. Leśniewski himself did not have an explicit classification of categories into kinds, like Russell before him, but such a classification was built up inside his system later by Ajdukiewicz (Ajdukiewicz 1935). According to it, there are *basic* categories and *functor* categories, which reminds one of the Fregean distinction between saturated and unsaturated expressions. Moreover, like in Frege's hierarchy of levels, and in Russell's simplified type theory, one finds only two basic categories in Leśniewski's system: sentences and names. All the other categories are functor categories.

Leśniewski's system forms a ramified ascending hierarchy of functor categories which are characterized in two ways: by the number and the semantic categories of the arguments and by the semantic category of the whole expression formed by the functor together with its arguments. Leśniewski's theory remained largely unknown outside Poland until 1935, when Ajdukiewicz gave it a more elegant formulation. It was intended to be applied to formal (constructed) rather than natural languages. Although Ajdukiewicz was more sensitive, at least in principle, to the latter, when he constructed his logical system, like Leśniewski, he limited his attention only to languages having two basic semantic categories: singular names (names of individuals) and general names (names of universals).

Ajdukiewicz added to Leśniewski's system an indexicalization of the semantic categories. To the basic categories of names and sentences he assigned the indices "n" and "s," respectively. To the functor categories he assigned a fractionary index consisting of a numerator and a denumerator. The former is the index of the semantic category of the value of the functor for its arguments. The latter is a sequence consisting of the indices of the semantic categories of the arguments.

Ajdukiewicz's categories are few in number and selected so that they fit the language of mathematics. He notices that the number of categories in ordinary language is much bigger, and there one has a fluctuation in meaning that renders the design of the system much more difficult. However, he points out that "In simple and favorable cases, however, the index apparatus cited above will be quite suitable for linguistic usage" (1935, 211).

We are now in a position to return to the initial question: What are the necessary and sufficient conditions for an expression to have unitary meaning? The necessary condition is for the expression to be *articulated throughout* (1935, 213). This means, first, that the expression may be divided into a *main functor* and its arguments. Ajdukiewicz is well aware that in ordinary language the order of the arguments in the main functor is not the same as its sequential ordering. Second, one has to check that each argument is also analyzable into a main functor and its arguments, and so on. Again, he points out that "ordinary language often admits elliptical expressions so that sometimes a significant composite expression cannot be well articulated throughout on the sole basis of the words explicitly contained in it. But a good overall articulation can be easily established by introducing the words omitted but implicit" (ibid., 213). The sufficient condition is that, after the division into functors and arguments, there must be a perfect fit between the number of arguments required by each functor and its actual arguments, which in addition must belong to the appropriate categories. An expression that fulfills both the necessary and sufficient condition has a unitary meaning, or, as Ajdukiewicz calls it, is *syntactically connected.* The matching of the functors' arguments with the semantic categories of the functors is checked mechanically by an algorithm that we now describe by way of an example. The sufficient condition is met if the result of this procedure is a simple index.

Ajdukiewicz gives the following simple sentence of mathematics (using parentheses instead of dots), where we write below each of its symbols the index of its category:

$$\begin{array}{ccccc} (p & \vee & p) & \rightarrow & p. \\ s & \frac{s}{ss} & s & \frac{s}{ss} & s \end{array}$$

We then arrange the parts of the expression into a main functor and its arguments:

$$\begin{array}{ccccc} \rightarrow, & p & \vee & p, & p. \\ \frac{s}{ss} & s & \frac{s}{ss} & s & s \end{array}$$

We apply the same procedure to any subexpression that can still be decomposed into a main functor and its arguments:

$$\begin{array}{ccccc} \rightarrow, & \vee\,, & p & p, & p. \\ \frac{s}{ss} & \frac{s}{ss} & s & s & s \end{array}$$

We next detach the sequence of indices of the expression:

$$\frac{s}{ss}\ \ \frac{s}{ss}\ \ s\ \ s\ \ s.$$

In the sequence thus obtained, we try, starting from left to right, to find a combination of indices so that we have a fractional index followed immediately by a sequence of indices that occur in the denominator of the fractional index. We cancel the sequence (if there are several, we cancel the first one), and replace it by the numerator of the fractional index. In our particular example, the combination we are looking for consists of the second, third, and fourth members of the sequence. The result is:

$$\frac{s}{ss}\ \ s.$$

We apply the same operation once more, and we get s.

This last index is the *exponent* of the expression. Because it is simple (and not fractionary), and all the others conditions have been fulfilled, our initial sentence is syntactically connected.

2.5. The Categorial Grammar of Bar-Hillel

Ajdukiewicz's theory was considerably developed by Bar-Hillel in a series of papers in the 1950's and 1960's (Bar-Hillel 1964, 1970). He shaped the concept of categorial grammar and popularized it to the English speaking world. As his predecessors, Bar-Hillel was interested in the question of the "unitary meaning" of a string of words. This problem was perceived even more acute in the 1950s, a period that sees the rise of computers and addresses the question of the feasibility of translation. As contrasted to his predecessors, Bar-Hillel was much more interested in the application of the tools of logic to ordinary language. He very much deplored the attitude of his teacher Rudolf Carnap, who, on one hand, developed very sophisticated mathematical tools to be applied to the study of language in general in *The Logical Syntax of Language* (Carnap 1937), but on the other hand found natural language too complicated to be studied with these tools. Carnap's attitude resumed in his *Introduction*,

> In consequence of the unsystematic and logically imperfect structure of the natural word-languages (such as German or Latin), the statement of their formal rules of formation and transformation would be so complicated that it would hardly be feasible in practise,

was, as we saw, symptomatic for most of the logicians working on the foundations of language (including Frege and the Polish school) and was regrettable for at least one reason. Carnap's work was what many linguists (including Zellig Harris and Noam Chomsky) read when they wanted to get acquainted with what logicians said about language. Comments like the ones just quoted would have and did eventually discourage them from seeing the relevance of some of the tools developed by logicians for solving problems in their own field. The Carnapian distinction anticipated by Husserl between formation and transformation rules would have been, as Bar-Hillel pointed out, highly relevant for studying the relation between, say, active and passive constructions in natural language undertaken much later by the generativists, especially if we recall that in Carnap's system both of them were formulated in *syntactic* terms.

One of Bar-Hillel's most important insights was that the theory of semantic categories as developed by Leśniewski and Ajdukiewicz was too rudimentary to be applied to the syntax of an ordinary language. For that purpose he improved Ajdukiewicz's theory in several directions. He noticed that Ajdukiewicz's notation α/β (this is the way he rewrote Ajdukiewicz's fractional index) for the functor categories makes it explicit that the functor is intended to apply only to an argument which occurs to its right. This was very clearly seen in the preceding section where Ajdukiewicz had only a right cancellation rule, which can be explicitly formulated as the following.

C1: Replace a string of two category symbols α/β, β by α. In symbols: α/β, $\beta \rightarrow \alpha$.

Bar-Hillel pointed out that this kind of rule makes the Leśniewski–Ajdukiewicz theory applicable only to formal languages that have explicitly that sort of structure, like the formal languages expressed in the parentheses-free Polish notation. In these languages, one has expressions like "$\cdot + abc$" (i.e., "$(a+b)\cdot c$" in the notation which uses parentheses) and "$+a \cdot bc$" (i.e., "$a + (b \cdot c)$"). But that system does not apply to natural language like English. For instance, in a very simple English sentence like *John died* the natural order is that in which the nominal *John* precedes the functor expression *died*: n, s/n.

But then the cancellation rule C1 is not applicable to it. The system would work only if we rewrite the above sentence as *Died John*. So one of the shortcomings of the Leśniewski–Ajdukiewicz grammar was the unidirectionality of its semantic categories, that is, the functor had to appear only on the left of the argument.

Bar-Hillel overcame this limitation by adding a new kind of functor category of the form $\alpha\backslash\beta$ where the functor operates now on arguments to its left. The new categories will now be more sensitive to the natural language syntax. These are the main categories used by Bar-Hillel (1964, 76):

Basic categories

Nominals: n

Sentences: s

Functor categories

Intransitive verbals: $n\backslash s$

Adjectivals: n/n

Intransitive verbal adverbials: $(n\backslash s)\backslash(n\backslash s)$

Binary operators: $s\backslash s/s$

And so on.

Corresponding to this, he also introduced a left-cancellation rule.

C2: Replace a string of two category symbols α, α/β by β. In symbols: α, $\alpha/\beta \rightarrow \beta$.

Another limitation in the Leśniewski–Ajdukiewicz grammar was the fact that to each expression there was assigned only one category. Consequently, each sentence had only one structural derivation. Such a limitation may be justified for artificial languages. But as pointed out by Carnap in his *Logical Syntax of Language*, in more complex languages one expression may belong to more categories (homonymy), and an expression may be ambiguous, that is, it may have more than one derivation. Accordingly, another improvement made by Bar-Hillel was to have expressions belonging to more than one category.

Applying these rules to a natural language sentence yields a derivation of that sentence. However, given that each expression may belong to several categories, its set of derivations may be rather large. An expression is well formed if it has at least one correct derivation. For example, consider the sentence:

(4) Little John slept soundly.

The dictionary will give us first the categories to which every word belongs. Thus we shall have *Little* (n/n), *John* (n), *slept* ($n\backslash s$), and *soundly* ($(n\backslash s)\backslash(n\backslash s)$). The next stage is to resolve the constituent structure of the sentence by the same mechanical procedure that Ajdukiewicz had used. The only difference is that now there are two cancellation rules that may be applied to a string of indices (Bar-Hillel 1964, 77). Let us illustrate how this procedure works in the case of (4).

We start with the sequence of indices of the subexpressions of (4):

(5) $$n/n, \quad n, \quad n\backslash s, \quad (n\backslash s)\backslash(n\backslash s).$$

We notice that there are three different ways to perform a cancellation, each of them resulting in one of the following sequences:

(6) a. $n, \quad n\backslash s, \quad (n\backslash s)\backslash(n\backslash s).$
b. $n/n, \quad s, \quad (n\backslash s)\backslash(n\backslash s).$
c. $n/n, \quad n, \quad n\backslash s.$

The sequence (6b) cannot be continued. The sequence (6a) can be continued by applying a cancellation rule to the first two members, after which we are in a blind alley, or by applying a cancellation rule to the second and the third member, the result being

(7) $$n, \quad n\backslash s.$$

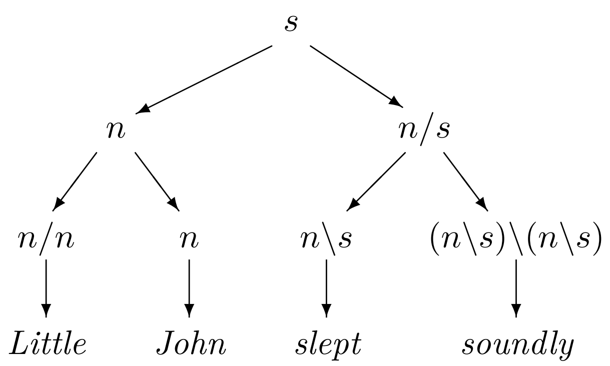
By applying a cancellation rule to this sequence, we reach the exponent s. The sequence (6c) can be continued, by applying a cancellation rule to its second and third members, after which we are in a blind alley, or by applying a cancellation rule to its first and second members, the result being

(8) $$n, \quad n\backslash s.$$

Finally, applying a cancellation rule once more, we reach the exponent s. Let us write down the two "successful" derivations.

1. $n/n,\ n,\ n\backslash s,\ (n\backslash s)\backslash(n\backslash s)$	1. $n/n,\ n,\ n\backslash s,\ (n\backslash s)\backslash(n\backslash s)$
2. $n,\ n\backslash s,\ (n\backslash s)\backslash(n\backslash s)$	2. $n/n,\ n,\ n\backslash s$
3. $n,\ n\backslash s$	3. $n,\ n\backslash s$
4. s	4. s

These two derivations differ from each other just in the fact that the cancellation step that occurs on the left side at stage two occurs on the right side at stage one. They are therefore equivalent, as can be seen from the fact that they give rise to the same tree expansion:



Things do not work so well, however, for more complex sentences like

(9) Paul thought that John slept soundly.

In this case, we get two derivations that are not equivalent. We are not going to exhibit the rather detailed analysis here (for the details, see Bar-Hillel 1964, 78–79). The important thing is that there are reasons to regard one of the two resulting derivation trees as unacceptable. So either the categorization is ill-chosen or the whole model is inadequate.

Problems are increased when we remember that for Bar-Hillel an expression may belong to several categories. For instance, *that* is sometimes a nominal (n) and sometimes an adjectival (n/n). *Thought* belongs to the categories n, $n\backslash s$, and $(n\backslash s)/(s/s)$ (*Paul thought John was asleep*). Thus the list of the category entries that the dictionary provides for some words may be rather long. In this case, the grammaticalness of some of the resulting derivations is highly dubious. In addition, the computational complexity of the process of constructing all the possible derivations is very high. The feasibility of the model decreases even more if we remember that the number of fundamental categories was very small. If we go on and add singular and plural, animate and inanimate, and so on, then the complexity becomes much bigger. Considerations of this sort made Chomsky (*Syntactic Structures*) very skeptical about the Bar-Hillel model. Actually Bar-Hillel himself came to the same conclusion (see section 4.1). A better linguistic model, according to him, is the transformational model of Harris (1957), and Chomsky (1957).

3. Truth-Conditional Semantics

The development of truth-conditional semantics starting in the works of Frege, Russell, Wittgenstein, and reaching the founding fathers of the field, Carnap and Tarski, is detailed in chapter 13. Here we only resume its main conclusions.

For the Polish logician Alfred Tarski, a semantic theory took the form of a theory of truth for a given language. The essential features of such a theory are laid down in his seminal paper, *The Concept of Truth in Formalized Languages* (1956). In designing a theory of truth for a given language, Tarski wanted to apply the methodology of semantic categories developed by his teacher, Lesńiewski (see previous discussion). This methodology is nothing else than the compositional method that requires that the syntax (grammar) of the language be specified in terms of explicit rules that dictate how expressions of appropriate categories combine themselves to form more complex expressions and finally sentences. The semantics, in this case the truth of a sentence, is then given by a set of semantical rules that mirror the appropriate rules of the syntax. But Tarski did not see any hope in his time to have a precise formulation of natural language ("colloquial language," as he called it) syntax, which had still to wait for the generative turn. In addition, he was fully aware that being semantically closed, natural language is beset by semantic paradoxes, and so he explicitly gave up the task of formulating a theory of truth for a natural language fragment. He believed that only a theory of truth for formalized languages is scientifically attainable. For Tarski, a formalized language is an interpreted one, like the language of arithmetic, and it can be given a precise syntactic representation.

For a formal language L, Tarski defined in the metalanguage ML (set theory) the predicate *truth-in-L*. For such a definition to be possible, for each expression of the object-language L there has to be an expression in ML which has the same meaning or translates it. The definition of *truth-in-L* is defined via the notion of satisfaction by induction on the complexity of formulas of the object-language L, as shown in chapter 9. The important thing to emphasize is that Tarski's theory presupposes the notion of translation or meaning.

In the late 1960s, Donald Davidson phrased Tarski's definition of the truth-predicate for a language L as an empirical theory, that is, a theory like any other in empirical sciences, with theoretical terms and axiomatic laws, from which logical consequences are to be derived which are then empirically tested. The purpose of such a theory is to give an answer to the question "What do we know that enables us to interpret the words of others?" (Davidson, *Radical Interpretation*, 125). Frege gave an analysis of the meaning of sentences, and Tarski a semantic analysis of the concept of truth for a formalized language. None of them was much interested in relating this semantic analysis to the actual behavior of the language users. Davidson is looking for much more: a theory that shows what one knows when one understands a language. The switch is clearer toward the active use of language and its interpretation. The details of Davidson's theory are described in chapter 13. Here is enough to point out that Davidson merged, in an ingenious way, an empirical setting that he had inherited from his teacher Quine with the Tarskian theory of truth: The language to be investigated is identified with Tarski's object language, the language of the investigating linguist with Tarski's metalanguage, and the correlation of the sentences of the former with those of the latter plays the role of the T-sentences. The major difference with Tarski is that the truth-predicate is now a primitive notion, not one to be defined. Tarski's requirement that for each expression in the object-language there be an expression in the metalanguage which is its translation, or has the same meaning, is not any longer the starting point of the inquiry but its outcome. The result of Davidson's undertaking under his reinterpretation of Tarski's theory of truth is broader than Quine's: not only a translation of the sentences of the target language into the sentences of the home language but also a systematic procedure that shows how the translation (meanings) of the former depends on their structure. This extra payoff was possible to achieve thanks to the Tarskian compositional definition of the notion of satisfaction.

Davidson wants his theory of truth to be a theory of meaning for a natural language, or a fragment of it. In laying the bases of his program for semantics, Davidson criticizes linguists and philosophers for having "exaggerated the difficulties in the way of giving a formal theory of natural language" (Davidson 1984, 55). In particular, what Davidson mostly refuses is the common conclusion that "there are two kinds of language, natural and artificial." This alleged difference would, in fact, correspond to the existence of some inherent features in natural language, which would act as insurmountable barriers forbidding a formal definition of truth in the same rigorous terms as the one provided by Tarski (1936) for logical languages. Not only is the existence of such barriers totally unwarranted, but the effort of pursuing a formal semantics theory of language is worthwhile because "in so far as we succeed in giving such a theory . . . , we see natural language as a formal system; and . . . we can think of linguists and analytic philosophers as co- workers" (ibid.).

The Davidsonian connection between truth and meaning of the kind Tarski has shown us how to construct, and which, as we have seen, finds its roots in Frege's work, has left a long-standing legacy in the interplay between logic and language inquiry in the last century. It is based on the compositional method of defining semantics on a rule-by-rule basis in tandem with a recursively defined syntax. It is, as we are going to see, the legacy embraced by Montague when he embarked on his project on "English as a formal language." It is, according to Montague, precisely this concern with truth-functional semantics that radically separates his project from the language paradigm emerging from the generative school, to which we now turn. However, at the end of our study, we are going to signal some interesting endeavors of combining the two (e.g., Higginbotham 1985, 1986).

4. Chomsky's Revolution in Linguistics

Prima facie the claim that logic and linguistics in the twentieth century would not have met without the development of generative grammar might easily be taken as an overstatement. Nonetheless, a closer analysis of what went on in the study of language in the late 1950s reveals that Chomsky's generative enterprise has actually been the precondition for any real and effective dialogue between new twentieth-century linguistics on the one hand and logic and philosophy on the other. This emerges with particular evidence if we take into account the character and methodological assumptions of pregenerative linguistics. Therefore, if among linguists it is still a matter of debate whether it is appropriate to regard generative grammar as a real revolution with respect to the past, from the point of view of logic and philosophy, using this term is not an overestimation. The breakthrough of *Syntactic Structures* (Chomsky 1957) goes far beyond the contribution to formal grammar provided by the theory of transformations. The rise of generative grammar actually represents the first appearance of contemporary linguistics into the debate on the universal structure of language. Actually, the Chomskian turn has ultimately resulted in an altogether new way of looking at language, different with respect to both traditional linguistics and logicophilosophical grammar.

4.1. The Birth of Transformational Generative Grammar

Linguistics experienced the first major change from the nineteenth-century tradition with the development of *structuralism*. Although this approach to the study of language stemmed more or less directly from the *Cours de linguistique générale* of Ferdinand de Saussure (1916), what is usually termed as structural linguistics should actually better be described as a family of linguistics schools, which, notwithstanding a common methodological overlapping, greatly differed in their conception of linguistic inquiry. What is mostly typical of structural linguistics is (i) the Saussurian distinction between *langue* and *parole*; (ii) the clear separation of the diachronic approach to language from the synchronic one, and the legitimation of the latter as an autonomous field of inquiry; and finally (iii) a conception of language as a structural system of signs—intended as arbitrary relations between a form (*significant*) and a content (*signifié*)—whose elements receive a value from their position in the system and from the reciprocal interrelations with the other parts of the system. Thus, structural linguistics essentially established itself as a taxonomic and paradigmatic inquiry, mostly consisting in the analysis of elements and the structure of the system of a specific language. Besides, a crucial feature of the structural approach to language in the first half of the century was the central role occupied by phonology and morphology with respect to syntax.[1]

Structural linguistics developed into various schools on the two sides of the Atlantic, but no real and significant relationship with logic blossomed in either cases. On the one hand, the Prague school of Troubetzkoy and Jacobson, and the Copenhagen circle of Hjelmslev, the leading representatives of European structuralism, mainly focused on developing respectively the Saussurrian notion of phoneme and its theory of linguistic signs. Moreover, they firmly regarded the study of language as part of human sciences, totally beyond the domain of any naturalistic, scientific, or formal inquiry. On the other hand, American structuralism with Edward Sapir and Leonard Bloomfield as its main representatives, was deeply oriented toward an anthropological study of language. Besides, Bloomfield's *Language* (1933) firmly established linguistics as an irreducibly empiricist scientific enterprise (thus differing from the mentalist approach of Sapir). By 1950s, the so-called post-Bloomfieldian school outnumbered the followers of Sapir's structuralism, so that the pre-Chomskian American linguistic environment was totally dominated by the empiricist paradigm. In contrast to European linguistics, Bloomfieldian structuralism tried to provide linguistics with the same scientific status as natural sciences. It was the particular conception of natural science that characterized the post-Bloomfieldian school that divorced the goals of empirical linguistics from the goals and the tradition of logical and philosophical grammar.

In fact, being deeply influenced by the empiricist philosophy of science of the Vienna circle,[2] Bloomfield himself and his followers regarded linguistics as an empirical science, to be studied with a strictly inductive and physicalist method. The purpose of linguistic inquiry was to "discover" the grammar of a particular language that emerges out of the stream of physical sounds produced by its speakers. Every abstract construct or generalization that could not be traced back to an empirical observation was to be ignored. Linguistics was thus merely *descriptive* and *taxonomical*, and linguistic investigation was strictly intended as the description of a *given* language and not of language *qua* language. Therefore, metatheory was limited to the formulation of a series of prescriptive rules that had to guide the discovery procedure of the grammarian. Linguistic inquiry was to be based on a merely external corpus of data, consisting mainly of physical records of the flow of speech. As a consequence, the judgments of the speakers were completely disregarded because of their alleged scientific unreliability. The analysis of a given language consisted in the discovery of four ordered levels of grammatical descriptions: phonemics, morphemics, syntax, and discourse. Similarly to European structural linguists, post-Bloomfieldian analyses almost exclusively concentrated on the first two levels. The inductive method of American structuralism, as well as its focusing on phonological and morphological descriptions of particular languages, also reveal the complete lack of any interest in the combinatorial nature of language and its syntactic creativity. The acknowledgment of the fundamental fact that language allows speakers to express an indefinite number of thoughts by combining finite resources—an issue already regarded as crucial by von Humboldt and Frege in the third of his *Logische Untersuchungen*[3] and which plays such a central role in logical grammar—was completely lacking in Bloomfieldian linguistics, as was the awareness of the recursive mechanisms of natural language. Consequently, there was no real interest in addressing the question of the general laws of syntactic combination of linguistic expressions.

This empiricist orientation also affected the way American structuralism approached the question of meaning. Semantics was excluded from the domain of scientific explanation in linguistics, and analyses grounded on semantic considerations were firmly denied. This represents another major difference between pregenerative linguistics and the work in the logical grammar tradition: From the point of view of Bloomfieldian methodology, any role assigned to semantic categories in deriving language composition would represent a dangerous and misleading confusion between formal and semantic considerations.

To summarize, by the middle of the 1950s, logic and the new science of linguistics lived in a "splendid mutual isolation" (Bar-Hillel 1969, 182). Harris deplored this attitude in a representative passage: "Whereas the logicians have avoided the analysis of existing languages, linguists study them" (Harris, 1951, 16 n17).

This situation dramatically changed with the publication of *Syntactic Structures* in 1957, which put the issue of the combinatorial nature of language and linguistic creativity at the core of linguistic inquiry, thereby laying the preconditions for the relevance of the work done in mathematical logic for linguistic theorizing. With a revolutionary move, Chomsky rejected the taxonomic and descriptive approach of post-Bloomfieldian linguistics and claimed "the linguist's task to be that of producing a device of some sort (called a grammar) for generating all and only the sentences of a language" (Chomsky 1957, 85). As a direct consequence of this methodological innovation, the domain of linguistics was enlarged from the description of a specific language to the theory of language structure itself. In Chomsky (1957, 50) a *condition of generality* is stated, according to which,

> we require that the grammar of a given language be constructed in accord with a specific theory of linguistic structure in which such terms as "phoneme" and "phrase" are defined independently of any particular language.

The overall goal of linguistics is thus the quest for the *universal principles* that make up the possibility of human language. This also led to a radical modification of the adequacy conditions for linguistic descriptions. In the Bloomfieldian tradition, a language description was adequate only in so far as it respected the methodological prescriptions that guaranteed its empirical and totally inductive nature. This view is, instead, firmly rejected by Chomsky (1957, 106): "The theory of linguistic structure must be distinguished clearly from a manual of helpful procedures for the discovery of grammars." In the Chomskian framework, a language description has to pass different levels of adequacy, the observational one being just the first. The top level of the adequacy conditions of a grammar, is what Chomsky calls its *explanatory adequacy*:[4]

> A linguistic theory that aims for explanatory adequacy is concerned with the internal structure of the device [*the generative grammar*]; that is, it aims to provide a principled basis, independent of any particular language, for the selection of the descriptively adequate grammar of each language. (Chomsky 1964, 63)

Linguistic description does not have to face only the tribunal of data, but also and more crucially the higher tribunal of the explanation of the general principles which lay at the basis of human creativity. Some of the direct consequences of this shift of perspective are the acceptance of speakers' grammaticality judgments as the fundamental empirical evidence, the introduction of abstract levels of representation of linguistic information, and the centrality of the investigation of the formal structure of grammars and linguistic rules.

The introduction—or rather the reintroduction—of the theme of linguistic creativity led to a direct connection between generative grammar and the rationalist, Cartesian tradition.[5] The rationalist turn not only switched the attention of linguists to the combinatorial nature of language, it also gave meaning a new and important role in linguistics. Linguistic creativity is, in fact, defined as the ability of understanding and generating an indefinite number of linguistic expressions, and the combinatorial power of language, identified with the generative nature of the syntactic component, is subservient to the goal of pairing a potentially infinite sound and meaning patterns.

Besides the breakthrough in linguistics, *Syntactic Structures* significantly contributed to the debate on the form of natural language grammar by showing the inadequacy of phrase structure grammars, and by introducing the first version of the *transformational generative* model. Chomsky's argument is focused on the claim that a theory of language structure based on phrase structure grammars "will be extremely complex, *ad hoc*, and 'unrevealing'" (Chomsky 1957, 34). Some of the most interesting examples brought by Chomsky to illustrate these faults concern the analysis of the auxiliary system in English and of the relations between active and passive sentences. The generation of all the possible combinations of auxiliaries verbs (e.g., *has taken*, *is taking*, *has been taking*, *is being taken*, etc.)—and the exclusion of all the impossible ones, represented an incredibly hard task for the phrase structure grammars available at the time. Much of the difficulty is due to the co-occurrence relation between the auxiliary and the morphological affix:

(10) a. *have -en* (perfect tenses)[6]
b. *be -en* (passive)
d. *be -ing* (progressive form)

Chomsky claims that while phrase structure grammars pay a very high price to capture such relations, the auxiliary distribution can easily be accounted for by assuming phrase rules that generate the discontinuous elements—auxiliary plus affix—as unit constituents, and then by positing a transformation rule that permute affix and verb to their surface position. This argument based on the simplification of the theory obtained by augmenting phrase structures with transformations is also applied to the analysis of passive sentences. In fact, formulating a proper rule that generates passive sentences requires taking into account a whole series of restrictions, such as the type of the auxiliary, the (in)transitivity of the verb, the type of the subject and of the object, and so on, which were extremely complex to express in terms of the existing context-free phrase structure formalisms. More generally, phrase structure grammars are judged to be inadequate to account for the context-sensitivity aspects of natural language, and last but not least, they are incapable to capture the fact that the application of a particular rule may require to look back to past stages of the derivation. For instance, to correctly describe the phenomenon of subject-verb agreement and thus generate the grammatically correct *The man runs*, while excluding the ungrammatical **The man run*, the rule that decides which affix to add to the verb must necessary look back to the stage of the derivation that had generated the subject noun phrase, and check whether it is singular or not.

The theory of grammatical description proposed by Chomsky to overcome the difficulties of phrase structure grammars is an abstract system of representations, made of three different layers: the *phrase structure component*, the *transformational component*, and the *morphophonemic component*. The phrase structure component is composed of phrase structure rules[7] that generate abstract sequences of constituents. The transformational rules, then, apply to some of these strings and convert them into other abstract strings with a different analysis of constituents. For instance, the following is the definition of passive transformation (Chomsky 1957, 43):

(11) If S_1 is a grammatical sentence of the form

$$NP_1 - Aux - V - NP_2,$$

then the corresponding string of the form

$$NP_2 - Aux + be + en - V - by + NP_1$$

is also a grammatical sentence.

The derivation of a sentence like *The book was taken by John* goes as follows:

(12) a. *John* – past – *take* – *the book.*
b. *The book* – past + *be* + *en* – *take* – *by* + *John.*
c. *The book* – *be* + past – *take* + *en* – *by* + *John.*
d. *The book was taken by John.*

The phrase structure rules generate the first level of representation formed by the sequence of phrase markers in (12a); then the passive transformation applies, yielding (12b), where the passive auxiliary + affix complex is inserted. The application of the auxiliary transformation distributes the participle affix to the main verb (12c). Finally, the morphophonemic rules apply to (12c), producing the sentence in (12d).

The introduction of derivations containing abstract terms, whose form and order can be quite far from the final output, and the important innovation of transformations that permute the elements during the derivation represented a radical departure from phrase structure grammars. Bar-Hillel et al. (1960) proved the equivalency with respect to their generative capacity between categorial grammars and context-free phrase structure grammars. In this way, the attack brought by Chomsky against the latter automatically extends to categorial grammars, whose inadequacy as a formal theory for natural language was ultimately recognized by Bar-Hillel himself:

> As a matter of fact, I had already noticed six years ago that the model did not work too well for complex sentences, but had rather hoped that this was due only to lack of refinement that could be partially remedied by increasing the number of fundamental categories, partly by additional rules. I have now come to realize that its failure in the more complex cases has a much deeper cause: the linguistic model on which this model was based is just not good enough. (Bar-Hillel 1964, 83)

It is important to remark that a large part of the innovative power of the arguments for transformations in *Syntactic Structures* also lies in the relevance assigned to certain types of syntactic phenomena for the evaluation of formal theories of grammar. Syntactic dependencies between discontinuous elements and constructions involving displaced or "moved" elements (e.g., passive and interrogative sentences) became core facts of natural language, and their characterization and proper treatment began to be regarded as necessary conditions for any theory aiming to provide an adequate description and explanation of the universal principles of language structure.

In the years that followed the publication of *Syntactic Structures*, the new generative paradigm rapidly conquered many spaces once dominated by Bloomfieldian linguistics. At the same time, the first transformation model underwent important modifications, especially thanks to an intense work directed to make explicit the exact nature of transformations and their classification. Finally, a more stabilized version of the transformational generative syntax—the so-called standard theory—emerged in 1965 with Chomsky's *Aspects of a Theory of Syntax.* The standard theory includes a syntactic component made of two abstract layers of representation: *deep structure* and *surface structure.* The level of deep structure is generated by the application of three sets of rules (base rules): *phrase structure rules*, *subcategorization rules*, and *lexical insertion rules*, the latter taking lexical items from the lexicon and inserting them into the phrase structure tree. In contrast to the 1957 model, where the recursive capacity of language was provided by generalized transformations—a particular type of transformations that take representations generated by phrase structure rules and embed one into the other (e.g., to form relative clauses or complex sentences)—in the *Standard Theory* the recursive power lies in the base rules, so that each derivation produces a single formal object that then enters the transformational component. Transformations produce the surface structure, which is then given as input to the phonological rules to derive the phonetic representation. We will see in section 5 how in the late 1960s, the standard theory became the starting point of an intense debate involving linguists, logicians, and philosophers on the relation between syntax and semantics, as well as concerning the nature of the deep structure representations.

4.2. The Autonomy of Syntax

With his critique of phrase structure grammars, Chomsky showed how linguistic theory in the form of a transformational generative theory can make its contribution to the analysis of the conditions of the possibility of human language. In that, he went much beyond the generative and explanatory resources reached by categorial grammars. In the same time, Chomsky's proposal represented a radical departure from the main tenets underlying the study of language universals in the logical grammar tradition by severing the link that related the analysis of syntactic structure to the semantic categories of grammatical terms. Almost at the end of *Syntactic Structures*, summing up the general view presented and defended throughout his book, Chomsky claims that: "Grammar is best formulated as a self-contained study independent of semantics. In particular, the notion of grammaticalness cannot be identified with meaningfulness" (Chomsky 1957, 106). Chomsky states here the well-known *principle of the autonomy of syntax*, which stands in deep contrast both to Husserl's idea that the principles of syntactic connection can be explained in terms of meaning connection rules (see section 2.2), and to Ajdukiewicz's principle according to which the well-formedness conditions of linguistic expressions depend on the "specification of the conditions under which a word-pattern, constituted of meaningful words, forms an expression that itself has a unitary meaning" (Ajdukiewicz, see section 2.3). Chomsky attacks these views by criticizing the equivalence of meaningfulness with grammaticalness. The notorious example (3) is intended to show that sentences without a unitary meaning can well be judged to be grammatical:

(13) Colorless green ideas sleep furiously.

And here are examples of ungrammatical sentences having a unitary meaning:[8]

(14) a. Have you a book on modern music?
b. *Read you a book on semantic music?
c. The book seems interesting.
d. *The child seems sleeping.

Chomsky argues that there is no semantic reason to prefer (14a) to (14b) and (14c) to (14d), besides the fact that there is surely a sense in which even the ungrammatical sentences have a unitary meaning exactly as their grammatical equivalents. The consequence was that only the independence from semantic considerations was seen to grant a reliable foundation for the search for the formal structure of language. It is, however, of crucial importance that independence neither means nor entails irrelevance. In other words, the autonomy of syntax is not a way to declare the structure and nature of the semantic component irrelevant with respect to the tasks of linguistic theory or to the architecture of the grammar of a language. On the contrary, the principle is regarded by Chomsky as the precondition of any attempt to tackle this issue seriously. There is no doubt that syntactic descriptions feed the semantic component and guide the composition of the interpretation of complex expressions:

> much of our discussion can be understood as suggesting a reformulation of parts of the theory of meaning that deals with so-called "structural meaning" in terms of the completely nonsemantic theory of grammatical structure. (Chomsky 1957, 103 n10)

Nonetheless, it is essential that structural descriptions must be defined independently of meaning and of general semantic considerations, that is, in purely formal terms, to be the formal, effective machinery for the derivation of semantic compositions.

The main aim of Chomsky's principle is therefore to provide a definition of syntax which is *nondependent* on semantics. Chomsky is actually always ready to accept the fact that semantics is one of the main guides for linguists' analysis. However, once a given analysis is suggested and enlightened by some semantic insight, it must ultimately be shaped in purely syntactic terms, that is, in terms of nonsemantic elements and rules. The revolutionary strength of the autonomy of syntax can hardly be questioned when we look at some of the examples in *Syntactic Structure*. For instance, Chomsky attacks the traditional idea that notions like grammatical subject or grammatical object have to be defined respectively in terms of the semantic notions of agent of an action and patient of an action. To this purpose, he brings striking counterexamples, like *John received a letter*, or *The fighting stopped*, where the grammatical subjects do not satisfy such semantic requirements. Chomsky's alternative proposal is to define subject and object in purely syntactic and formal terms, that is, by means of particular configurations of syntactic descriptions. Later on, notions like agent or patient also entered the theory as *thematic roles*,[9] and played a crucial part at the *Government and Binding* stage of Chomsky's theory.

As we pointed out in the section on Frege, there is a striking similarity between Chomsky's redefinition of grammatical subject, and what Frege says in his *Begriffsschrift* about the same notion. In the same way as Frege wanted to set logic free of its old grammatical connotations, thereby dismissing the logical relevance of problematic and jeopardized concepts like that of subject, in 1957 Chomsky wants to define the crucial grammatical notion of subject independently of any semantic considerations, for that would prevent one, according to him, from reaching a rigorous definition.

Syntactic rules drive semantic compositionality, but the critical point is whether this can be explained by a priori positing the uniformity between syntactic and semantic processes, and especially by defining the former in terms of the latter. Chomsky's view is rather that syntactic and semantic features match to the point of allowing language to do its job—that is, carrying complex thoughts by means of finite combinatorial resources—but this match is not complete. The truly empirical issue is therefore to evaluate the extension of the correspondence between syntax and semantics, or better the extension of the mismatch that still makes language possible. Chomsky's claim that the relation between form and meaning in language must be tackled by assuming syntactic representations whose form and conditions feed meanings but do not depend on them was actually repeatedly challenged in the late 1960s and 1970s. Stemming directly from within the generative enterprise, the generative semantics movement brought a strong attack on the thesis of the autonomy of syntax, by defining "deep syntax" as actually a logico-semantic level. Not very differently, Montague presented a new model of logical grammar according to which—thanks to a proper pairing of semantic and syntactic operations—sentences are analyzed in such a way as to exhibit the logical form directly on their syntactic sleeves.

4.3. Semantic Theory in Early Generative Grammar

The problem of the relations between grammatical description and their interpretation had a central role in generative linguistics since its very beginning. Linguistic creativity is, in fact, defined as the ability of understanding sentences, and the combinatorial power of language is subservient to the goal of pairing sound and meaning patterns:

> The grammar as a whole can thus be regarded, ultimately, as a device for pairing phonetically represented signals with semantic representations, this pairing being mediated through a system of abstract structures generated by the syntactic component. (Chomsky 1964, 52)

The standard theory is actually a model for the cognitive architecture of the language faculty, as composed of three independent modules, that is, *the syntactic component*, *the phonological component*, and *the semantic component*. Generative linguistics, thus, reestablished the centrality of language as a system of sound-meaning pairs, and thereby recovered De Saussure's main insight, which was lost in the empiricist version of American structuralism due to its incapability to integrate the role of meaning in a scientific theory of language in other than behaviorist stances. Chomsky's negative remarks on current theories of meaning that he blamed for using the term meaning as a "catch-all term to include every aspect of language that we know very little about" (Chomsky 1957, 104), was certainly directed against the behaviorist approaches to meaning framed in terms of stimulus-reaction patterns, as well as against any approach making use of intensions, sentential truth conditions, conditions for nondeviant utterances, distribution, and rules of use (Katz and Fodor 1963, 480). Thus from the very beginning, the approach to the study of meaning in generative grammar is characterized by a strenuous opposition against every externalist characterization of the semantic component, be it formulated in terms of behaviorist Skinnerian models,[10] or truth-conditional semantics so typical of the logical grammar tradition. In fact, according to Chomsky (1964, 77), "explanatory adequacy for descriptive semantics requires ... the development of an independent semantic theory ... that deals ... with the question: what are the substantive and formal constraints on systems of concepts that are constructed by humans on the basis of presented data?"

The burden of giving a shape to the semantic component within the standard theory was taken by J. J. Katz and J. Fodor with *The Structure of a Semantic Theory* (1963), which represents the first attempt to develop a semantic theory consistent with the generative approach to language:

> A semantic theory describes and explains the interpretative ability of speakers: by accounting for their performance in detecting the number and content of the readings of a sentence; by detecting semantic anomalies; by deciding upon paraphrase relations between sentences; and by marking every other semantic property or relation that plays a role in this ability. (Katz and Fodor 1963, 486)

Describing the interpretive ability of speakers requires tackling what Katz and Fodor call the *projection problem*, that is, determining the compositional procedure by which speakers are able to interpret an infinite number of linguistic expressions by combining a finite repository of meaningful expressions through an equally finite set of rules. The projection problem is now supposed to be solved by the descriptions associated with the syntactic component of the transformational generative grammar which is specified independently and is autonomous of the semantic module. Thus, according to Katz and Fodor (1963, 484), "linguistic description minus grammar equals semantics," and, as a consequence, the role of semantics is purely *interpretive*, that is, it *merely* provides an interpretation of the syntactic descriptions. This approach, a direct corollary to the principle of the autonomy of syntax, stands in deep contrast to the approach of categorial grammars, where the semantic categories of lexical items, with their basic distinction between basic and functor categories, are supposed to drive the "syntactic connexity" of the complex linguistic expression. In the architecture of the standard theory, the syntactic composition is guaranteed by the syntactic component, while the semantic module assigns meanings to the lexical items and then projects from them, up along the syntactic tree, the unitary meaning to be assigned to the complex expression.

The semantic theory (*KF*) proposed in Katz and Fodor (1963), further developed in Katz (1972), has two components, the *dictionary* and the *projection rules*. The former assigns to every lexical item an entry consisting of its grammatical category and a semantic part describing its possible *senses*. Each sense is in turn described by means of a list of *semantic markers* (e.g., [Human], [Male], etc.) and a *distinguisher*. Together these elements "decompose the meaning of a lexical item (or one sense) into its atomic concepts, thus enabling us to exhibit the semantic structure in a dictionary entry and the semantic relations among the various senses of a lexical item" (Katz and Fodor 1963, 496). Semantic markers are intended to express those aspects of a sense that are systematic with respect to the language and give rise to basic semantic oppositions among senses. In this way, their role becomes similar to that of features in phonology, from which they are actually inspired. On the other side, distinguishers represent the idiosyncratic and unsystematic aspects of the sense of a lexical item. Once the lexical items that appear as leaves in a syntactic tree are assigned a dictionary entry, the projection rules compose these entries along the paths of the syntactic tree. This projection does not take place according to the function-argument schema typical of the Fregean tradition, but through a process of unification of the corresponding clusters of semantic markers and distinguishers, thus producing all the possible readings to be associated to the complete sentence.[11]

The notion of projection rules actually represents a common element of both *KF* and of the semantic analysis of meaning to be proposed in *Montague grammar*: In both cases, semantic rules pair syntactic formation rules. On the other side, the conception of the lexicon in *KF* is completely different from the corresponding notion in logical semantics and logical grammar, and is surely one of the weakest and most attacked part of the theory. Where in categorical grammars the lexical organization takes place according to the function-argument distinction, the dictionary has a fairly standard lexicographic organization, as also remarked by Bar-Hillel (1970, 185), who criticizes the theory for its "identification of semantics with lexicology." As Katz (1972) claims, *KF* is actually intended to be a theory of sense and not a theory of reference, and truth and truth-conditions have thus no role to play in it. Semantic interpretation and meaning representation are rather achieved through a process of semantic decomposition, by assuming a fairly traditional "chemical view on concepts"[12]—typical of the rationalist analyses in the eighteenth century—according to which the sense of a lexical item is analyzed in terms of its basic conceptual bricks. However, the introduction of semantic markers as the technical device that performs the task of lexical decomposition and deals with concept combination does not help overcome the difficulties of the lexicographic definitions of senses pursued in *KF*. Besides, the usage of semantic markers was heavily criticized for its complete lack of real explanatory power as far as meaning is concerned, since, as Lewis (1972, 169–170) claims, "translation into Latin might serve as well."

Besides its own specific problems, *KF* has provoked one of the strongest disagreements between the new theory of grammar in generative linguistics and the logicophilosophical approach. For instance, Katz attacks the idea of logical form based on the distinction between form and content (Katz 1972, xvii), and claims that formal logic cannot provide a proper semantics for natural language because of its being exclusively concerned with the logical form of sentences, which in turn heavily depends on the contribution of logical words like connectives, quantifiers, and so on.[13] According to Katz, the truly semantic facts to be explained are those that philosophers called *analytic*, that is, truths and inferences based not on the structural properties of syncategorematic words (e.g., quantifiers and connectives) but rather on the lexical content of words, like (15), which should equally well deserve the status of logical truth:

(15) If x is a bachelor, then x is an unmarried adult man.

The importance and centrality assigned to the characterization of lexical meaning and lexical inference represents a genuine and positive contribution that *KF* brought to the semantic debate, independently of the problems of the formal representation of the semantic level offered by the theory. According to it, one of the main tasks of a semantic theory is to capture the contrast between, for instance, *The dog chases the cat* and *The cat chases the dog*, which differ semantically, despite having the same structural description. Thus *KF* shifts the focus from issues of purely compositional semantics—which on its view are basically solved by the proper formulation of a syntactic component paired with projection rules—to the issue of how to characterize lexical meaning. This stands in deep contrast to the conception of the logical grammar tradition, where semantic categories are carved out mainly to drive semantic composition, but fails to provide satisfactory insights into lexical content. The interest in the lexical aspects of meaning will constantly grow in the later stages of semantic inquiry in theoretical linguistics, and will largely influence the research in model-theoretic semantics, which will, in some cases, also incorporate and develop the formal treatment of lexical decomposition.[14]

Katz (1972) considers the failure of logical theory to deal with the core semantic aspects of language as another consequence of "the rise and eventual dominance of empiricism" (xxi) with its behavioristic perspective on meaning. Actually, *KF* should properly be regarded as another episode in the Chomskian program with its systematic opposition against empiricist approaches to language. *KF* attempts to develop a fully internalist, rationalist, and intensionalist analysis of meaning and semantic inference:

> Empiricists claim that concepts of the theory of meaning are unscientific, occult and useless, and should be banished from a scientific theory of language. ... Thus, the constructive task for the rationalist approach to the study of language is to reply to these claims in the only way that can ultimately discredit them, that is by building a linguistic theory which demonstrates the scientific soundness of concepts such as sense, meaning, synonymy, analyticity, and so on. (Katz 1972, xxiii)

The heart of the polemics is the analytic-synthetic distinction and the notion of synonymy criticized by Quine, both related to his argument against any mentalist conception of meaning not reducible to purely behaviorist assumptions. When applied to nonlogical words, Quine finds the notion of analyticity based on that of synonymy as totally unreliable and inherently circular:

> But there is a second class of statements, typified by (2):
>
> (2) No bachelor is married
>
> The characteristic of such a statement is that it can be turned into a logical truth by putting synonyms for synonyms; thus (2) can be turned into [No unmarried man is married] by putting "unmarried man" for its synonym "bachelor." We still lack a proper characterization of this second class of analytic statements, and therewith of analyticity generally, inasmuch as we have had in the above description to lean on a notion of "synonymy" which is no less in need of clarification than analyticity itself. (Quine 1953a, 23)

In addition, Quine attacks the notion of synonymy as a pure relation between the senses of the words. Synonymy should instead be approached only "from the point of view of long segments of discourse" (Quine 1953b, 57; see also Quine 1960). Again, Quine's purpose is to substitute the notion of synonymy as meaning-sharing with the behavioristic notion of approximate likeness of the effects provoked by linguistic expressions on a hearer. With respect to these empiricist arguments, the theory of sense pursued in *KF* is, therefore, an attempt to develop an internalist theory of meaning, based on the conceptual analysis of word senses. The theoretical device of semantic markers is intended to provide a new foundation for the notion of word meaning and for the semantic relations of analyticity and synonymy *qua* relations between word meanings.

5. Deep Syntax and Generative Semantics

One of the most interesting aspects of the period from the late 1960s up to the mid-1970s is that philosophers and linguists found an unprecedented ground of agreement in carrying a strong attack against the model of grammar proposed by Chomsky in *Aspects* in 1965. This atmosphere is best illustrated by the volume *Semantics of Natural Language*, edited by D. Davidson and G. Harman in 1972, which contains contributions by generative linguists, logicians and philosophers, whose unifying leitmotif is the refusal of the purely syntactic nature assigned to deep structure representations in Chomsky's standard theory. The common claim is that deep structure is to be identified with logical form, that is to say, deep structure must be equated with the place in which the hidden logical structure of natural language is explicitly encoded. On the linguistic side, the convergence with logic was mainly carried out by J. McCawley, G. Lakoff, and other representatives of the *generative semantics* movement, the harsh opposition movement to the Chomskian theory of grammar, which quickly developed in 1968 to then rapidly decline around

1973–1974. The relevance of this heterodox movement stemming out of the body of Chomskian linguistics actually goes far beyond its short life and the particular linguistic solutions and analyses proposed by its representatives, most of which were soon to be dismissed. Crucially, starting from the assumption that "the linguists' and the logician's concerns are consistent with each other" (McCawley 1972, 540), generative semantics was able to raise a whole wealth of issues concerning the relation between grammatical structure and logical form, thus showing the inadequacies of the first transformational models to tackle these aspects of the theory of language. Many problems that attracted the attention of generative semanticists, like quantification, bound anaphora, and so on, continued then to occupy a key position in the later developments of the Chomskian framework, leading toward more elaborated hypotheses on the syntax-semantic interface.

As we saw in section 4, Chomsky's main claim is that syntactic representations must be designed strictly independently of semantics, which instead forms a separate module within the architecture of grammar. In the standard theory, deep structure occupies a particularly prominent role: It is, in fact, the level at which subcategorization and selectional restrictions are defined, grammatical relations are established, and lexical items are inserted from the lexicon. Moreover, deep structure also represents the main, actually the only interface with semantics. In fact, the relation between the syntactic component and the semantic module is regulated by the so-called *Katz–Postal hypothesis* (Katz and Postal 1964), according to which all the syntactic information necessary for the semantic interpretation is provided by deep structure. In other words, transformations are all meaning-preserving, since they do not affect the interpretation of syntactic structures. This hypothesis perfectly fits with the interpretive role assigned to the semantic component in *KF*, where the projection problem is intended to be solved at the syntactic level by the representations provided as input to the semantic rules, which have a strictly interpretive role. In fact, projection rules in *KF* are actually quite trivial, since they simply have to compose the semantic markers of the lexical items all up the syntactic tree.

One of the most crucial consequences of assuming the Katz–Postal hypothesis as the basis for the syntax-semantics pairing is that every nonlexical semantic ambiguity must be explained in terms of a difference at the level of deep structure. This is simply a corollary to the fact that all the structural information which determines semantic composition is already encoded in the deep structure, together with the fact that transformations cannot affect meaning. However, crucial problems arise with the analysis of sentences containing logical operators and quantifiers. For instance, (16a) is semantically ambiguous between a reading in which the negation has wide scope over the adverbial clause, and one in which it has narrow scope. Similarly, (16b) is ambiguous between a reading in which the universal quantifier has wide scope over the existential one, and a reading in which the universal quantifier has narrow scope:

(16) a. I don't steal from John because I like him.

b. Everyone loves someone.

The problem is that, given that deep structure is assumed to represent the only interface with semantics, such ambiguities can be accounted for only in terms of structural differences at this level of representation. To tackle this issue, Lakoff (1970) proposes to represent the ambiguity in (16a) at the level of deep structure by associating two readings with it:

(17) a. [$_S$ Neg [$_S$ I steal from John] [because I like John]].

b. [$_S$ [$_S$ Neg I steal from John] [because I like John]].

Similarly, Lakoff (1972) explains the scope ambiguity in (16b) by claiming that the reading in which the universal quantifier has wide scope derives from the deep structure (18a), while the reading in which the universal quantifier has narrow scope derives from the deep structure (18b):

(18) a. [$_S$ [Every x] [$_S$ [Some y] [$_S$ love x y]]].

b. [$_S$ [Some y] [$_S$ [Every x] [$_S$ love x y]]].

The scope of a quantifier, thus, includes whatever it *commands*, that is, every constituent dominated by the constituent dominating the quantifier.[15]

The crucial novelty in this line of analysis is that deep structure is now regarded as an abstract level with the same format as first-order logic representations. In other words, first-order quantificational representations are syntactically "wired" in deep structure syntactic representations. Accordingly, the latter contain not only lexical items but also abstract elements, such as variables, quantifiers, and other logical operators, like negation, modalities, and so on. These abstract constructs are then converted into surface phrase structures by the application of various types of transformations—such as, for instance, quantifier lowering—which replaces and inserts lexical items or deletes some of the abstract elements. To summarize, pushing to the extreme the assumption that deep structure provides all the compositionally relevant semantic information, generativist semantics was led to abandon the idea that deep structure is purely syntactic, thus breaking radically with the principle of the autonomy of syntax and the overall architecture of Chomsky's standard theory. Instead of postulating syntactic representations that serve as input to the interpretive semantic component, semantics is now conceived as a generative device that produces the deep layer—directly encoding the logical form of sentences—which is then converted by various transformations into surface structures. Therefore, generative semantics came to defend the view that in grammar "there is no dividing line between syntax and semantics" (McCawley 1972, 498), given that many logicosemantical phenomena—ranging from quantifier scope, to presuppositions, implicatures, and speech acts[16]—are represented directly as the level of deep structures. According to Lakoff (1972, 647), linguistics merges in this way with *natural logic* conceived as "the empirical study of human language and human reasoning." However, the price generative semanticists had to pay to achieve this progressive "logicization" of deep structures is the enormous complication of the transformation apparatus necessary to fill the wider and wider gap between deep and surface structure, due to the more and more abstract nature of the former.

Given the trend of regarding deep structures as abstract representations, they actually ceased to contain lexical items altogether, and progressively turned into predicate-argument structures familiar from first-order logic. Again, this shift stemmed from the need to solve important issues arising in the standard theory, like the representation of the so-called selectional restrictions. For instance, in (19), the verb *sink* has similar selectional restrictions with respect to its transitive and intransitive versions: The *NP* in the object position in (19a) has the same relation with the predicate as the *NP* in the subject position in (19b). There is, however, a difference between the two which consists in the presence of an extra *NP* in (19a) with the role of the agent causing the event described by the predicate:

(19) a. *John sank the boat.*
b. *The boat sank.*

On the hypothesis that selectional restrictions between a predicate and its arguments are determined at the level of deep structure (as claimed by the standard theory), one has now to analyze (19a) as derived from a deep structure representation containing as its proper part the structure associated with (19b). Lakoff analyzes (19a) as derived from the deep structure representation (20):

(20) $[_S$ John CAUSED $[_S$ the boat sink$]]$.

The predicate CAUSE in small caps marks the fact that it is actually an abstract item, which is then incorporated into the main predicate by a transformation which produces the transitive, agentive version of *sink*. This type of analysis has been extended to other causative verbs, such as *kill* that Lakoff took it to be equivalent to CAUSE-DIE, and so on.

The radical departure from the autonomy of syntax and the progressive logicization of deep structure pursued by generative semanticists found an incredibly high resonance among philosophers and logicians. For instance, Harman (1972) argues for the complete identification of deep structure with logical form regarded as the result of the paraphrase of a sentence into quantificational notation of the kind exemplified by (18). Moreover, following again generative semanticists, the subject-predicate asymmetry is considered as a surface feature of sentences, whose deep syntactic description is instead totally isomorphic with the standard predicate-arguments structure familiar from logic. Harman (1972, 30) arrives at the conclusion that "it is interesting to observe that what holds for logic holds for deep structure as well."

The idea that the deep structure of generative linguistics should be identified with logical form is also argued for by D. Davidson in *Semantics for Natural Languages* (1970). Adopting this stance allows for the possibility to view language inquiry as a common enterprise between linguists, logicians and philosophers:

> It is a question how much of a realignment we are talking about for linguistics. This depends largely on the extent to which the structure revealed by a theory of truth can be identified with the deep structure transformational grammarians seek. In one respect, logical structure (as we may call the structure developed by a theory of truth) and deep structure could be the same, for both are intended to be the foundation of semantics. (Davidson 1984, 63)

We find here two important points that make a difference with respect to the conception of language embodied in the standard theory, and which anticipate some of the crucial features of *Montague grammar*. First of all, logical form is to be identified with one of the levels of grammatical description, which in the case of transformational grammars is the deep structure level. Second, a proper semantics for natural language should take the form of a theory of truth, which assigns to sentences their truth-conditions in a recursive way. In particular, the claim that "a semantic theory for natural language cannot be considered adequate unless it provides an account for the concept of truth for that language along the general lines proposed by Tarski for formalized language" (Davidson 1984, 55) represents a major departure from Chomsky's radically internalist perspective on the study of language, which, as we saw with Katz and Fodor, rejected logical and truth-based approaches to the study of meaning. Although Davidson agrees with Chomsky that semantic differences in sentences sharing the same surface structure (e.g., *I persuaded John to leave* versus *I expected John to leave*) have to be accounted for in terms of differences at the level of deep structure, he claims, nevertheless, that these "intimations of structures" have to be derived ultimately from a suitable theory of truth which yields, for each sentence, its truth-conditions. The reader is referred to chapter 13 for the detailed description of Davidson's theory of truth. For him, it is such a theory that must serve as a ground for the notion of grammaticalness itself and must reveal the structure of sentences, which therefore is to be seen "through, the eyes of a theory of truth" (Davidson 1984, 61). One could not be further away from the principle of the autonomy of syntax. In a similar vein, Lewis (1972) argues for a referential, truth-conditional semantics for natural language, and at the same time claims that the ultimate criterion of adequacy for the grammar of a given language is its suitability to yield the truth-conditions of sentences in a recursive way.[17] To sum up, there is something common to both generative semanticists and certain logically minded philosophers of language: Both saw the convergence between logic and linguistics to be achievable only to the extent one abandons Chomsky's idea that the syntactic description of natural language is to be carried out independently of semantic constraints: "if we regard the structure revealed by a theory of truth as deep grammar, then grammar and logic must go hand in hand" (Davidson 1984, 59).

The idea that the logical form of sentences differs from their surface structure is a leitmotif in twentieth-century logic and analytic philosophy. It is therefore understandable that one of the crucial tenets of Chomskian linguistics, that of the surface structure being derived from a deep structure representation through various transformations, raised a huge amount of expectations concerning the possibility of finally identifying the level of linguistic description at which logical form is explicitly encoded. However, as we saw, these expectations could be really met only to the extent deep structures were conceived in a completely different way from that in which Chomsky himself conceived them. The deep structure in the *Aspects* was designed to be the interface with semantics and not encode logical form and other structural semantic properties. The move in this direction occurred with the reinterpretation of deep syntactic structures in generative semantics, a move that come to have an important influence in the first stages of the development of model-theoretic semantics. The reason of this influence is that it makes possible for the first time to see the relation between grammar and logic as internal, nonaccidental:

> Not all theories of linguistic structure guarantee that such a correspondence (*between grammatical structure and logical structure*) is not accidental. For example, the theory given in Chomsky's *Syntactic Structures* leaves open the question as to whether such correspondences are accidental. . . . Any rules relating English sentences to their logical forms would be independent of the rules assigning those sentences grammatical structures, though the rules assigning logical form might or might not depend on the grammatical structures assigned by rules of grammar. To the extent to which a theory of grammar assigns grammatical form independently of meaning, to that extent that theory will be making the claim that any correspondence between grammatical form and logical form is accidental. (Lakoff 1972, 546–547)

Chomsky has always claimed that such a correspondence exists, although its extension and form have to be established on empirical grounds. Apart from being a non sequitur, Lakoff's statement is a clear substantiation of the claim that to capture the evident correlation between syntax and semantics, syntactic rules should be couched in semantic terms. This idea is extremely close to the approach pursued by Montague in designing the formal architecture of language. According to it, grammatical forms are not determined independently of meaning, and the rules assigning grammatical structures to sentences run parallel to the rules that derive their logical form.

6. Montague Grammar and Model-Theoretic Semantics

In section 3.2 we mentioned Davidson's truth-functional program for the semantics of natural language, a challenge addressed to both logicians and linguists. At the beginning of the 1970s, Davidson's challenge was accepted by Richard Montague, who shared a similar view on the relation between artificial and natural language, as stated in the *incipit* of *English as a Formal Language* (1970) (Montague 1974):

> I reject the contention that an important theoretical difference exists between formal and natural languages. On the other hand, I do not regard as successful the formal treatments of natural languages attempted by certain contemporary linguists. Like Donald Davidson I regard the construction of a theory of truth ... as the basic goal of serious syntax and semantics; and the developments emanating from Massachusetts Institute of Technology offer little promise towards that end. (Montague 1974, 188)

In the short period of his activity, Montague pursued this goal by developing a rigorous formal system to describe the syntax and the semantics of natural language, as well as the relation between them, within the tradition of logical grammar. In particular, this was achieved by defining a fully compositional model-theoretic semantics in the spirit of Tarski (1936) and Carnap (1947), which also heavily relied on recent results in modal logic (Kripke 1963) and the foundations of intensional logic (Kaplan 1964).

What is usually known as Montague grammar (MG) corresponds roughly to the formal theory of natural language laid out by Montague in *English as a Formal Language* (EFL) (1970), *Universal Grammar* (UG) (1970), and *The Proper Treatment of Quantification in Ordinary English* (PTQ) (1973). Montague's work did not come out of the blue, but rather stood out in a research environment in which the possibility of exploiting the tools of logic for a formal description of natural language had come to a complete maturation and ramified into many directions. Thus, the term "Montague grammar" itself should be enlarged to include the important contributions made by Lewis (1972), Cresswell (1973), and many others, who together with Montague have been responsible for opening the field of model-theoretic semantics. Still, it is not possible to deny the central role occupied by Montague's own contribution, whose influence largely and rapidly outclassed other formal models for natural language semantics, particularly because of the extreme rigor with which the formalization of syntax and semantics was carried out in *MG*, as well as for the relevance and variety of linguistic phenomena to which Montague applied his system in the three papers.

Montague's work had a tremendous impact among both logicians and linguists, with the character of a true revolution. He managed to show that natural language, or some important fragments thereof, is amenable to formalization, thus bannishing the skepticism expressed by Carnap and Tarski before him. Moreover, Montague has also revealed the relevance and power of various logical tools—such as possible worlds semantics, intensional logic, higher-order logic, type theory, lambda calculus, and so on—for the purposes of providing a satisfactory formal description of natural language. However, this last claim has raised much concern. It is, in fact, quite controversial whether Montague's appeal to higher order logic and intensional logic is not only fully justified but also truly effective to tackle the problems it intends to address, thus making the departure from first-order logic unnecessary. Actually, this is one of the major points of disagreement between him and Davidson, who does not share Montague's appeal to possible world semantics. Still, it is undeniable that a large part of the logical machinery employed nowadays in formal semanticists derives form the logical tools underlying *MG*.

On the linguistic side, as Bach (1989) notices, the major advancement brought by Montague was to prove that natural language can be regarded as a formal system at the interpretive side, too. In fact, Chomsky's revolution had revealed that natural language can be satisfactorily described as a formal system at the syntactic level, but semantics was still regarded as lying largely beyond the possibility of such a treatment. Because of the deep mistrust in the application of logical techniques to semantic analysis, and of the suspicions toward truth-conditional semantics—particularly due to the Chomskian internalist and psychologist stand on language—semantic inquiry in the first years of generative linguistics was largely dominated by the *KF* paradigm, based on the decompositional analysis of meaning in terms of semantic markers. As we pointed out in section 4.3, *KF* has a strong lexicographically oriented approach to semantic analysis. The focus of the semantic analysis undertaken by Katz and Fodor is the representation of word senses, and of relations among them, such as analyticity, synonymy, semantic anomaly, polysemy, and so on. Although this new perspective on lexical meaning appears quite remarkable, still the inadequacies of the theoretical framework of *KF* have made the enterprise quite unsatisfactory. Among other things, unlike the truth-conditional approach, *KF* has been criticized for not being explanatory in a substantial way, given that semantic markers alone cannot provide any effective insight into interpretive processes. Despite heavily relying on lexical decomposition, generative semanticists should be given the credit for calling the linguists' attention to the centrality of problems such as quantification, operator scope, pronominal anaphora, and so on that pertain to the issue of logical form. Yet the quite protean and adventurous nature of generative semantics was not really able to lead to a solid framework within which to tackle these issues. The multilevel syntactic architecture typical of generative linguistics, notwithstanding its importance to overcome the shortcomings of traditional phrase structure grammar, had raised the important question of determining which representational layer is the input to semantic interpretation. The situation had become even more complex with the debate about the Katz–Postal hypothesis and the proposal advanced in generative semantics to regard deep structure as semantic in nature. In summary, few real advancements have been made on the issue of setting the relation between syntax and semantics on solid grounds, let alone of giving it a formal foundation. This situation partly justifies Montague's criticism (1974, 223) against transformational grammar:

> One could also object to existing syntactical efforts by Chomsky and his associates on grounds of adequacy, mathematical precision and elegance. ... In particular, I believe the transformational grammarians should be expected to produce a rigorous definition, complete in all details of the set of declarative sentences of some reasonably rich fragment of English ... before their work can be seriously evaluated.

Montague was actually able to provide a mathematically precise, logical analysis of a specific subfragment of English. But the revolutionary import of his contribution lies above all in the general framework he set up to formalize the relation between the logical semantics and the syntactic structure of natural language.

6.1. Compositionality and Universal Grammar

According to Frege (1984, 390),

> even if a thought has been grasped by an inhabitant of the Earth for the very first time, a form of words can be found in which it will be understood by someone else to whom it is entirely new. This would not be possible, if we could not distinguish parts in the thought corresponding to the parts of a sentence, so that the structure of the sentence can serve as a picture of the structure of the thought.

In this perspective, therefore, the *principle of compositionality*— stating that the interpretation of a complex expression is a function of the interpretations of its parts—is the key ingredient to explain linguistic creativity. Compositionality is usually satisfied by logical languages, in which the definition of semantics runs parallel to the recursive definition of syntax, like in the case of Tarski's definition of the satisfaction predicate. Actually, compositionality provides a finite method for the semantic interpretation of an infinite number of expressions.

On the other hand, Chomsky has claimed that the explanation of linguistic creativity cannot be based on the assumption of a systematic pairing between syntax and semantics: Unlike formal languages, he did not find this correspondence warranted for natural languages. Thus, the capacity of understanding and producing a potentially infinite number of sentences would rather be grounded in the generative capacity of the syntactic component, which can and must be identified independently of any semantic considerations. Syntactic rules generate structures that in turn drive semantic composition belonging to an external interpretive module. This kind of architecture of the grammar, having at its center the principle of the autonomy of syntax, is strongly criticized by Montague, who rejects the possibility of considering a syntactic theory of language, independently of semantic considerations. Actually, the main objection that Montague addresses to transformational grammar in *UG* is exactly its lack of relevance for the enterprise of developing a semantics for natural language.[18] He thinks that

i. A proper semantic theory must be grounded on a theory of truth, and

ii. The core function of syntax is to provide the necessary structural backbone for semantic interpretation.

Thus, while for Chomsky (1957) the purpose of syntax is to generate the grammatical sentences of a language, for Montague syntax is mainly subservient to the goal of defining how the interpretation of a sentences depends on the interpretations of its components. In other terms, in the case of Montague the problem of finding the right syntactic structure becomes part of the problem of how to implement the requirement of compositionality.

Consistent with his tenet that no actual difference exists between formal and natural language, Montague solves the problem of the interpretability of a potentially infinite number of sentence in the same way as Frege (Montague 1974, 217). Interpreting means for him determining the truth values of sentences, something to be achieved

> by assigning extra-linguistic entities to all expressions involved in the generation of sentences (including among these, sentences themselves) in such a way that (a) the assignment of a compound will be a function of the entities assigned to its components, and (b) the truth value of a sentence can be determined from the entity assigned to it.

UG represents the most general formulation of Montague's formal framework, where the principle of compositionality is given an algebraic formulation in terms of an homomorphism between a syntactic algebra and a semantic algebra. The algebraic perspective allows Montague to specify the structure of syntax, the structure of semantics and the relation between them by abstracting away from specific ontological and epistemological commitments, as well as from the particular format of the syntactic rules. The aim of the paper is to provide the universal architecture of syntax, semantics, and of their relation. However, it is crucial to keep in mind that the term *universal* in Montague has a radically different content and import than in generative linguistics. In the latter, universal grammar means the rules and principles that define the class of human learnable languages and that form the innate component of the faculty of language, while in the former universal grammar intends to capture the constraints on the structure of whatever possible language, artificial or natural.

In *UG*, the *syntax* is defined as the system $\langle A, F, X_\delta \rangle_{\delta \in \Delta}$, such that:

(21) i. $\langle A, F \rangle$ is an algebra with A a nonempty set of expressions, and F a set of operations on A;

ii. Δ is the set of syntactic categories;

iii. for all $\delta \in \Delta$, X_δ is a subset of A, that is, the set of basic expressions of category δ (e.g., intransitive verbs, common nouns, etc.).

The operations in F apply to tuples of basic expressions to generate other expressions like A. For instance, F may include a simple operation like concatenation, or any other operation of arbitrary complexity. This algebra generates a *disambiguated language*, the set of all expressions which can be formed starting from some basic expressions and applying operations on them a finite number of times. An *interpretation* for the disambiguated language is a system $\langle B, G, f \rangle$, such that:

(22) i. $\langle B, G \rangle$ is the semantic algebra similar to $\langle A, F \rangle$, such that B is the set of meanings prescribed by the interpretation, G is the set of semantic operations corresponding to the syntactic operations F and which apply to tuples of elements in B;

ii. f is a function from $\mathrm{U}_{\delta \in \Delta} X_\delta$ into B, that is, it assigns meanings to the basic expressions of the generated language.

G may contain operations like function-argument application, function composition, and so on. Crucially, given the system $\langle A, F, X_\delta \rangle_{\delta \in \Delta}$ and the interpretation $\langle B, G, f \rangle$, the meaning assignment to the generated language is defined by Montague as the unique *homomorphism* g from $\langle A, F \rangle$ into $\langle B, G \rangle$ such that:

(23) i. F and G are sets of operations with the same number of places;

ii. g is a function with domain A and range included in B;

iii. for every n-ary operation F and G and every sequence $a_1, \ldots, a_n$ in A, we have $g(F(a_1, \ldots, a_n)) = G(g(a_1), \ldots, g(a_n))$;

iv. $f \subseteq g$.

The principle of compositionality is implemented as the homomorphism requirement, and not an isomorphism requirement, to allow for the fact that two distinct syntactic expressions may have the same meaning, but each syntactic expression must have at most one meaning. Defining the compositionality as a homomorphism between two algebras requires a disambiguated level of representation in syntax. This is not, however, what happens in natural language, where the same linear sequence of elements can be structurally ambiguous, for example, in the case of *Every man love some woman* or *John saw a man in the park with a telescope*, etc. To account for this fact, in addition to defining a disambiguated language DL generated by an algebra, Montague also defines a *language* L as the pair $\langle DL, R \rangle$, where R is a relation with domain in A. R maps expressions of A onto expressions of A, which so to speak represent their surface representation. This relation is often referred to as an "ambiguating" relation,[19] because it maps expressions of a disambiguated language onto expressions to which more than one syntactic description may correspond. So, an expression ζ of the language L is ambiguous if and only if there are at least two expressions ζ' and ζ'' generated by the relevant algebra such that $\zeta' R \zeta$ and $\zeta'' R \zeta$. This solution amounts to saying that a language may contain expressions to which there actually correspond two different syntactic representations generated by the syntax. The interpretation is defined on the disambiguated algebra: If ζ is an expression of the language L and g the homomorphism of the interpretation, then g means b if and only if there is a $\zeta' \in DL$, such that $\zeta' R \zeta$ and $g(\zeta') = b$. This implies that an ambiguous expression will also have two or several interpretations, each corresponding to a particular syntactic representation.

In MG the principle of compositionality is implemented in terms of the so-called *rule-by-rule interpretation* (Bach 1976). According to this procedure, the syntax is given by a recursive definition starting from a set of basic expressions of given categories with rules that operate on them to produce new expressions. Here is an example with F_I an arbitrary syntactic operation:

(24) *Syntactic Rule* S_I
If α is a well-formed expression of category A and β is a well-formed expression of category B, then γ is a well-formed expression of category G, such that $\gamma = F_i(\alpha, \beta)$.

Semantics is then given by a parallel recursive definition, in which basic expressions are assigned basic semantic values, and for each syntactic rule S_I there is a semantic rule of the following form:

(25) *Semantic Rule* S_I
If α is interpreted as α' and β is interpreted as β', then γ is interpreted as γ', with $\gamma' = G_k(\alpha', \beta')$.

G_k is a semantic operation (e.g., function-argument application) that combines the semantic values of expressions to produce the semantic value of the complex expression. The rule-by-rule interpretation is actually the method that is normally employed to define the interpretation of formal languages, and is employed by Montague in PTQ to provide a compositional formal semantics of English. When the systems of rules that make up the syntax and the semantics are recast as algebras, the rule-by-rule correspondence becomes the requirement of homomorphism. So again, the framework defined in UG is intended to provide the most general method to satisfy the constraint of compositionality.[20]

Because Montague's goal is to define a theory of truth for a language, the notion of interpretation just given is not per se sufficient, given that it is simply defined as a particular type of mapping between algebras without further constraints on the format of semantics, consistently with the full generality of the approach pursued in *UG*. This is the reason why Montague introduces the notion of *Fregean interpretation*, a semantic algebra consisting of a model-theoretic structure containing domains with a typed structure. The extensive use of type-theory and intensional logic to define the formal semantics of natural language is one the most important innovations brought by Montague. Actually, in the years immediately preceding the three papers devoted to the formalization of English, Montague did important work in intensional logic, leading to the unification of temporal logic and modal logic and more generally to the unification of intensional logic and formal pragmatics, defined by Bar-Hillel (1954) as the study of indexical expressions, that is, words and sentences whose reference cannot be determined without knowledge of the context of their use. In addition, Montague integrated the work of Carnap (1947), Church (1951), and Kaplan (1964) into a fully typed intensional logic, in which the function-argument structure typical of type theory (Russell) merges with the functional treatment of intensions. The latter are in fact regarded by Montague as functions from possible-world and time moments to extensions. The results of this more foundational work are contained in *Pragmatics* (1968), *On the Nature of Certain Philosophical Entities* (1969), and *Pragmatics and Intensional Logic* (1970).

To guarantee that the mapping from the syntactic to the semantic algebra is a homomorphism, it is necessary that the model-theoretic structure contains a domain of interpretation for every syntactic category. In *UG* and in *PTQ*, Montague defines recursively an infinite system of domains via an intensional type theory, and then establishes a relation between syntactic categories and a relevant sets of defined types.[21] Montague first defines the set of *types* T in the following way:

(26) i. e is a type;

ii. t is a type;

iii. if a and b are types then $\langle a, b\rangle$ is also a type;

iv. if a is a type, then so is $\langle s, a\rangle$.

Each type individuates a certain domain, which will provide the interpretation of the expressions of the language having this type. Thus in (i)–(ii) the two basic types, e and t are introduced. Their interpretation varies: In *UG* and *PTQ* e is the type of entities, and t is the type of truth values, while in the *EFL* system, t is the type of propositions defined as functions from possible worlds to truth values. The clause in (iii) defines the functional types, that is, the types of functions from objects of type a to objects of type b. Finally, the clause in (iv) defines the intensional types, that is, the types of functions from indices (usually possible worlds or world-time pairs) to objects of type a. Notice that the type s has no independent existence, that is, it does not belong to the domain of objects of the structure itself, and does not represent the interpretation of any category of expressions.

Given a nonempty set A (to be regarded as the set of entities or individuals), a set I of possible worlds, and a set J of moments of time, for every type $\tau \in T$ Montague recursively defines the domain associated to τ, $D_{\tau,A,I,J}$ (*the domain of possible denotations of type* τ *relative to* A, I, *and* J) in the following way:[22]

(27) i. $D_{e,A,I.J} = A$;

ii. $D_{t,A,I,J} = \{0, 1\}$;

iii. $D_{\langle a,b\rangle,A,I,J} = D_{b,A,I,J}^{D_{a,A,I,J}}$;

iv. $D_{\langle s,a\rangle,A,I,J} = D_{a,A,I,J}^{IxJ}$.

In *PTQ*, the domain $D_{\langle s,a\rangle,A,I,J}$ is defined as the set of *senses* (*meanings* in the *UG* terminology) of type a,[23] regarded as intensional entities, that is, functions from pairs of indices to objects of type a.

The relation between the syntactic categories of a language L and the semantic types is determined by a function of *type assignment*, defined as the function σ from Δ (the set of syntactic categories) into T, such as $\sigma(\delta_0) = \tau$. Finally, a *Fregean interpretation* for L is defined as an interpretation $\langle B, G, f\rangle$ such that for some non-empty sets A, I, J and type assignment σ:

(28) i. For every type τ, B includes at least the domain of possible denotations for τ, that is, $B \subseteq \mathrm{U}_{\tau \in T} D_{\tau,A,I,J}$;

ii. For every syntactic category δ, such that $\sigma(\delta) = \tau$, and every basic expressions $\zeta \in X_\delta$, $f(\zeta) \in D_{\tau,A,I,J}$;

iii. For every syntactic operation F_I there is a corresponding semantic operation G_I, such that if F_I applies to expressions of category δ' to produce expressions of category δ'', then G_I applies to entities of type $\sigma(\delta')$ to produce entities of type $\sigma(\delta'')$.

The system defined by these rules is then applied to two specific examples, the language of *intensional logic*, and a fragment of English, with the purpose of showing that the same procedure allows both formal and natural languages to be treated alike. The fragment of English formalized by Montague is very complex, including intensional verbs, relative clauses, quantifiers, and so on. Before giving some of the details of Montague's analysis, it is important to spend a few words to describe two notions that play a crucial role in *MG*, namely, the *method of fragments* and the *method of indirect interpretation*.

The former, one of the novelties of Montague's approach, made its first appearance in *EFL*. It consists in writing a complete syntax and truth-conditional semantics for a specific fragment of a given language to make fully explicit assumptions employed in the formalization.

The method of indirect interpretation consists of interpreting a fragment of a given language via its translation into a formal language, which is in turn interpreted in a Fregean structure. It contrasts with the method of direct interpretation where the syntactic algebra, the semantic algebra (corresponding to the Fregean interpretation), and the homomorphism between them are given explicitly. The direct method is employed by Montague in *EFL* to formalize a fragment of English, while in *UG* and *PTQ* the indirect method is adopted, with intensional logic serving as an intermediate language into which the fragment of English is translated. Montague provides a general theory of *compositional translation*, in which a homomorphism g is built up between the syntactic algebra Syn_1 defining the source language L_1 and the syntactic algebra Syn_2 defining the target language L_2, for which, in turn, there is a homomorphism h with a semantic algebra *Sem* which provides an interpretation for L_2. Because one can define an operation of composition of g with h and show it is a homomorphism k from Syn_1 to *Sem*, then it follows that *Sem* may serve directly as an interpretation for the source language L_1. In other words, the compositionality of translation makes the intermediate level totally dispensable. Nevertheless, the compositionality of translation provides, according to Montague, a more perspicuous representation of the logical form of expressions, thus making the indirect method of interpretation preferable as a way to define a formal semantics for a given fragment of English.

6.2. PTQ: The Standard Model of Montague Grammar

The formal analysis of the fragment of English presented in *The Proper Treatment of Quantification in Ordinary English* (*PTQ*) represents an illustration of the general algebraic method for a compositional analysis of language exposed in *UG*. This paper is the best vantage point to see at work Montague's approach to natural language, not only because the fragment discussed there is the largest of the three that Montague formalized, but also because it is the paper that had the strongest impact on the linguistic community and on the subsequent development of model-theoretic semantics. Thus, *PTQ* represents a sort of standard model of *MG* up to the point of being almost identifiable with it.

In *PTQ*, the *syntax* of the fragment of English makes use of a categorial grammar reminiscent of Ajdukiewicz's system, whose set of categories *Cat* is defined as the smallest set X such that:

(29) i. $t \in X$, with t the category that corresponds to sentences (the letter t marks the fact that sentences are the expressions that can have a truth value);

ii. $e \in T$, with e the category of entities;

iii. If A, $B \in X$, $A/B \in X$ and $A//B \in X$.

The "double-slash" category is the only actual innovation brought to Ajdukiewicz's categorial grammar, and it is used only to mark the syntactic difference from A/B. That is to say, A/B and $A//B$ are semantically alike, although they have a different syntactic role. The set *Cat* contains an infinite number of categories, out of which only a restricted number is actually used in *PTQ*, which is listed in table 16.1, together with the abbreviations given

Table 16.1 SYNTACTIC CATEGORIES IN *PTQ*

Category	*Abbreviation*	*Linguistic description*	*Example*
t/e	IV	Intransitive verb phrases	run, walk
t/IV	T	Terms	John, Mary, he_0, he_1, ...
IV/T	TV	Transitive verb phrases	find, eat, seek
IV/IV	IAV	IV-modifying adverbs	slowly, allegedly
t//e	CN	Common nouns	man, unicorn, temperature
t/t		Sentence-modifying adverbs	necessarily
IAV/T		IAV-making prepositions	in, about
IV/t		Sentence-taking verb phrases	believe that, assert that
IV//IV		IV-taking verb phrases	try to, wish to

to some of them by Montague and their standard linguistic equivalent. The "double-slash" category is, for instance, used to distinguish IV from CN: In fact, while semantically they are both interpreted on the domains of functions from individuals to truth values, at the syntactic level IV combine with terms to produce sentences, while CN are used to build up terms. For each of the categories listed in table 16.1, Montague introduces a set of basic expressions, some of which are exemplified in the fourth column. Basic expressions form what we might call the lexicon of the selected fragment of English, although it is important to notice that in many respects it greatly differs from the linguists' conception of lexicon. For instance, the categories IV/t and IV//IV contain basic expressions like *believe that* or *try to*, which are not lexical under a strictly linguistic point of view. Similarly, the basic expressions belonging to category T, include, besides proper nouns, an infinite set of variables, he_0, he_1, $he_2, \ldots$, which play a crucial role in Montague's analysis of relative clauses, quantification and anaphora. Moreover, one of the characteristics of *MG* is that there is no expression in the language, neither basic nor derived by syntactic rules, belonging to the category *e*. Thus, this category is only used to create other categories, but, in Montagovian terms, it has no linguistic exemplification.

The grammar of *PTQ* includes the set of syntactic rules described in (24), which generate the set of expressions of various categories (sentences included). The categories determine which expressions are to be combined with which, as well as the category of the resulting expressions. In contrast to the categorial grammars of Ajdukiewicz and Bar-Hillel (see section 2.5), the syntactic operations include a rule of concatenation. Montague introduces 17 syntactic rules, grouped in five clusters. Some of the *rules of functional application* (S4–S10) coincide with mere concatenation, other rules of the same group include operations that inflect the verb to the third singular person of the simple present, to satisfy the agreement with the subject, or inflect a pronominal variable to the accusative form, when it combines with a transitive verb. In the cluster of *basic rules* (S1–S3), S2 introduces the determiners *every*, *the*, and *a* syncategorematically,[24] while S3 is a rule for forming relative clauses. The *rules of conjunction and disjunction* (S11–S14) introduce *and* and *or* syncategorematically, and the *rules of tense and sign* (S17) inflect a verb for tenses other than present (future and present perfect) and adds negation. Finally, the *rules of quantification* (S14–S16) replace a variable inside an expression with a term: These rules have a crucial role in Montague's treatment of scope and quantification, as we will see in 6.2.3. The *meaningful expressions* of the given fragment of English are those generated by the finite application of the syntactic rules to the basic expressions. The way a sentence is constructed through a finite application of the set of syntactic rules is called by Montague the *analysis tree* of the sentence.

The Montagovian conception of grammar greatly differ from the generative-transformational grammars, both from a formal and a substantial point of view. First of all, the syntactic operations operate on strings and not on trees or labeled bracketing. The analysis tree marks the history of the derivation leading to a meaningful expression, but it is not in itself a symbolic object which can be manipulated and transformed by syntactic rules. Second, there is no notion of grammaticalness other than that of meaningfulness, in agreement with Montague's rejection of Chomsky's autonomy of syntax. Therefore, the syntactic rules in *MG* resemble more Husserl's meaning connection rules and the rules of traditional logical grammar, rather than the rules of the syntactic component in generative grammar. The structure of the analyses tree in *MG* is intended to reflect meaning constitution and semantic structural ambiguities, and not so much purely syntactic criteria of constituency.

PTQ implements the algebraic framework set up in *UG* in terms of a rule-by-rule interpretation procedure described in section 6.1. Since the interpretation is performed according to the indirect method, syntactic rules are actually paired with translation rules into the language of intensional logic (*IL*), which is then interpreted in a Fregean structure through a homomorphic mapping. Notice that Montague's rule-by-rule method bears some similarities to the projection rules which in *KF* operate on tree structures (see 4.3). However, the similarity should not hide a deeper difference between the two: In *KF* the projection rules provide an interpretation to an autonomous syntactic component, while in *MG* the rules of syntax are designed in such a way as to display the semantic structures.

Given the set of types T defined in (26), the set ME of meaningful expressions of *IL* includes an infinite number of constants and variables for each type $\tau \in T$, and a set of expressions generated by a list of recursive rules. *IL* is then interpreted in a (*Fregean*) *interpretation* or *intensional model*, which is a quintuple $M = \langle A, I, J, \leq, F \rangle$, such that:

(30) i. A, I, and J are nonempty sets, the domain of individual entities, the set of possible worlds, and the set of moments of times, respectively;

ii. for every type $\tau \in T$, $D_{\tau,A,I,J}$ is the set of possible denotations of τ, as defined in (27);

iii. $\leq$ is a linear order over J;

iv. F is a function taking as arguments constants of *IL*, such that for every type $\tau \in T$ and every constant α of type τ, $F(\alpha) \in D_{\langle s,\tau\rangle A,I,J}$.

As we pointed out in 6.1, for every type τ, the domain $D_{\langle s,\tau\rangle A,I,J}$ corresponding to $D^{IxJ}_{a,A,I,J}$, is called by Montague the set of *intensions* or *senses* of expressions of type τ. Intensions—which Montague regards to be the equivalent to Fregean senses—are defined as functions from world-time pairs $\langle i, j\rangle$, to entities of appropriate type. The *extension* (or *denotation*) of a certain expression with respect to the pair $\langle i, j\rangle$ is obtained in the standard way by application of the intension function to the argument $\langle i, j\rangle$. Montague interprets the constants of *IL* as intensions (30iv), and then, given an assignment g, he recursively defines the notion of *extension with respect to M and g* for all the *ME* of *IL*.

The lambda calculus is an important part of *IL*, the intermediate language employed in the interpretation of English. Here are some central definitions:

(31) i. If $\alpha \in ME_a$ and u is a variable of type b, then $\lambda u\alpha \in ME_{\langle b,a\rangle}$;

ii. If $\alpha \in ME_{\langle a,b\rangle}$ and $\beta \in ME_b$, then $\alpha(\beta) \in ME_b$;

iii. If $\alpha \in ME_a$ then $[\hat{}\alpha] \in ME_{\langle s,a\rangle}$;

iv. If $\alpha \in ME_{\langle s,a\rangle}$ then $[\check{}\alpha] \in ME_a$.

Given an expression of type a and a variable of type b, the extension of an expression like $\lambda u\alpha$ (31i) is a function belonging to the domain $D_{\langle b,a\rangle,A,I,J}$, which associates with every argument x of type b the value that α has when the variable u denotes x. Montague must be given credit for introducing lambda calculus into the linguistic community, to whom it was virtually unknown before him. This calculus has rapidly become one of the most powerful tools for the formal description of natural language semantics. Montague himself used lambda expressions for the analysis of relative clauses, conjunction, and quantification.

In (31ii) we find another crucial ingredient of *MG*, *functional application*: The expression $\alpha(\beta)$ denotes the result of applying the function denoted by α to the argument denoted by b. That is to say, the extension of $\alpha(\beta)$ is the value of the extension of α, when applied to the extension of b. Moreover, every expression γ of type $\langle a, t\rangle$ denotes a set B of entities of type a, or equivalently the *characteristic function* of B, that is, the function from the domain of entities of type a to $\{1, 0\}$, such that it assigns 1 to all the entities that are elements B, and 0 otherwise. Then, if γ has type $\langle a, t\rangle$ and α has type a, "we may regard the formula $\gamma(\alpha)$ ... as asserting that the object denoted by α is a member of the set denoted by γ" (Montague 1974, 259).[25]

Finally, (31iii, iv) introduce operators that move back and forth between an expression and its intensional type. The "ˆ" (up or cap) operator takes an expression α and forms a new expression denoting the intension of α: The extension of $^\wedge\alpha$ is then the intension of α. The "ˇ" (down or cup) operator performs the reverse operation when applied to intensional types. Thus, the extension of $^\vee\alpha$ with respect to a certain pair $\langle i, j\rangle$, is the result of applying the intension of α to $\langle i, j\rangle$, that is to say, it is the extension of α at $\langle i, j\rangle$.[26]

Given the indirect method adopted in *PTQ*, the bulk of the interpretation procedure consists in providing a compositional translation from English into expressions of *IL*, which takes place in three steps.

First, a mapping f is introduced, defined on the categories of English with arguments in the types T, so that every English expression of category A is translated into an expression of *IL* of type $f(A)$. The mapping is defined as follows:

(32) i. $f(e) = e$,
ii. $f(t) = t$,
iii. $f(A/B) = f(A//B) = \langle\langle s, f(B)\rangle, f(A)\rangle$, for every category A and B.

The particularity of this definition lies in the third clause. In fact, it states that functional categories (such as IV or T, etc.) correspond to a function from intensions of objects of type $f(B)$ to objects of type $f(A)$. That is to say, expressions of functional types are always translated into expressions of *IL* which denote functions operating on the intensions of their argument. For instance, in *PTQ* expressions of category CN or IV are assigned the type $\langle\langle s, e\rangle, t\rangle$, where $\langle s, e\rangle$ is the type of what Montague refers to as *individual concepts,* that is, functions from world-time pairs to individual entities. As it will be seen in 6.2.2, the reason for this choice lies in the analysis of the expressions creating intensional contexts. In particular, the use of individual concepts and the characterization of IV and CN expressions as sets of individual concepts are motivated by Montague by the failure of the following argument:[27]

(33) a. *The temperature is ninety.*
b. *The temperature is rising.*
c. *Ninety is rising.*

The fact that the truth of (33c) does not follow from the truth of the two premises can be explained in the following way: The value of a number word like *ninety* is always equal to itself in every point of reference in which it is evaluated, but this is not true for noun phrases like *the temperature* or *the price*, whose denotations can change from context to context (temperatures and prices can rise and fall). Montague (1974, 267–268) accounts for this difference by assuming that a noun phrase like *the temperature* does not denote an individual entity, but a function from world-time pairs to individual entities (i.e., an individual concept), and that the IV *rise* is inherently intensional, that is, "unlike most verbs, depends on its applicability on the full behavior of individual concepts, not just on their extension to the actual world and ... moment of time." In this way the failure of (33) is seen to follow from the fact that in (33b) the verb *rise* applies to an individual concept denoted by a subject noun phrase, while the identity in (33a) holds between the individual entity ninety and the individual entity that is the extension of the individual concept denoted by *the temperature* at the actual world and moment of time. In his attempt to grant the maximum level of generality to the formal framework for the interpretation of the English fragment, Montague generalizes the interpretation of *price* and *rise* as sets of individual concepts to every IV and CN, while the fully extensional behavior of other elements of these categories is captured through meaning postulates (see 6.2.1.). However, Montague's explanation of (33) as well as his interpretation of IV and CN as functions of individual concepts has been widely criticized. Actually, the idea of individual concepts soon became quite controversial, and Bennett (1974) proposed an amendment to Montague's type-assignment to syntactic categories which assumes no individual concepts at all and in which IV and CN are assigned the type $\langle e, t\rangle$. As a result, the function f in (32) can be redefined as follows:

(34) i. $f(e) = e$,
ii. $f(t) = t$,
iii. $f(\text{IV}) = f(\text{CN}) = \langle e, t\rangle$,
iv. $f(A/B) = f(A//B) = \langle\langle s, f(B)\rangle, f(A)\rangle$, for every category A and B.

This amendment has led to a major simplification of the translation procedure, which has quickly found its way in standard expositions of *MG* (e.g., Dowty et al. 1981) and will also be assumed in the rest of this chapter to describe the formalization of the English fragment in *PTQ*.[28]

The second step of the translation procedures takes care of the translation of the lexical items, that is, of the basic expressions, into *IL*. To this purpose, Montague defines a function g defined on the set of basic expressions, except for the verb *be*, sentence modifying adverbs (e.g., *necessarily*), and basic expressions of type T, that is, proper nouns and variables (see table 16.1), all of which are translated into complex logical expressions of *IL*:

- the verb *be* is translated as $\lambda P \lambda x\,{}^{\vee}P({}^{\wedge}ly(x = y))$, which has type $\langle\langle s, \langle\langle s, \langle e, t\rangle\rangle, t\rangle\rangle, \langle e, t\rangle\rangle$;
- *necessarily* is translated as $\lambda p \Box {}^{\vee}p$, which has type $\langle\langle s, t\rangle, t\rangle$;
- the translations of proper nouns and variables will be discussed in section 6.2.1.

All other lexical expressions are translated as constants of *IL* of appropriate type. For instance, the intransitive verb *walk* of category IV is translated into the constant *walk*$'$ of type $\langle\langle s, e\rangle, t\rangle$, which denotes a function from individual concepts to truth values.

In the third step of the procedure for compositional translation, Montague provides a translation rule for each syntactic rule that generates a meaningful expression of the English fragment. A sample of the 17 translation rules proposed in *PTQ* will be closely inspected in the following sections, discussing some of the most influential and controversial solutions offered in *MG* for the characterization of the logical form of natural language, that is, the analysis of noun phrases (6.2.1), the treatment of intensional constructions (6.2.2), and the representation of scope ambiguities (6.2.3). However, as a general remark, it is worth emphasizing that for Montague the function-argument application, which appears in the interpretation of all the basic grammatical relations, is the fundamental semantic glue. In fact, in *PTQ* all the nonbasic semantic types are constructed as functional types. This way of building the semantic interpretation of complex expressions represented an absolute novelty for the linguistic community and had an enormous impact. This procedure stands in deep contrast to the procedure of semantic composition in *KF*, which is performed through a process of unification of feature clusters in which functional application had no role to play. Montague's extensive use of function-argument structures in semantics brought to a new life the machinery of categorial grammar, neutralizing some of the criticisms levelled against it by Chomsky on account of its limited explanatory power. Given a function-argument based semantics, categorial grammar seemed to offer a very good syntactic layer to build a fully compositional model-theoretic semantics for natural language, especially if it is enriched in such a way that it can handle the structural complexity of natural language. As we showed, one such emendation was performed by Montague himself in *PTQ*, when he used categorial grammar to define the mapping between syntactic categories and semantic types as the basis for the homomorphic translation: He did not limit the operation of syntactic composition to concatenation. As Partee and Hendriks (1997, 30) remark, while in classical categorial grammar the derivation tree that displays the application of the syntactic rules is isomorphic to the surface structure of the relevant string, in *PTQ* this is no longer true, and "it is the analysis tree which displays the semantically relevant syntactic structure."

6.2.1. The Interpretation of Noun Phrases

In *PTQ*, proper names, pronouns, and noun phrases prefixed by determiners like *every* or *the* belong to the same syntactic category of terms, T, despite the fact that the first two are basic expressions, while determiners are introduced syncategorematically via syntactic rules. Because T = t/IV, then given (34), every term is assigned the type $\langle\langle s, \langle e, t\rangle\rangle, t\rangle$. The type $\langle s, \langle e, t\rangle\rangle$ is the type of functions from world-time pairs to sets of individuals, and is called by Montague the type of *properties*. Thus terms are regarded as denoting sets of properties, or equivalently functions from properties to truth values. This approach resembles Frege's analysis of quantifiers as second-order concepts: In *PTQ* a noun phrase like *every man* is a second-order predicate, true of a property of individuals if every individual that is a man has that property. For instance, the sentence *Every man dreams* is interpreted as stating that the property of dreaming has the property of being true of every man. *PTQ* provides the following translation rule (T2) for phrases containing the determiners *every*, *a/an* and *the*, where P is a variable of type $\langle s, \langle e, t\rangle\rangle$, and x and y are variables of type e:

(35) If ζ is of category CN and translates as ζ', then:

a. *every* ζ translates into $\lambda P \forall x[\zeta'(x) \to {}^{\vee}P(x)]$;

b. *the* ζ translates into $\lambda P \exists x[\forall y[\zeta'(y) \to x = y] \wedge {}^{\vee}P(x)]$;

c. *a/an* ζ' translates into $\lambda P \exists x[\zeta'(x) \wedge {}^{\vee}P(x)]$.

A major difference between the *PTQ* analysis of noun phrases and Frege's analysis is the view of proper names, which in the former are interpreted as sets of properties.[29] While in Frege proper names denote objects, that is, individual entities, in Montague their type is the same as that of quantificational expressions, $\langle\langle s, \langle e, t\rangle\rangle, t\rangle$. Thus the translation of a proper name like *John* is $\lambda P {}^{\vee}P(j)$, with j a constant of type e which denotes the individual John, and the denotation of the name *John* is the set of properties that John has. Montague's analysis is careful to obey the principle of compositionality as a strict architectural constraint on the semantics for natural language: Proper names belong to the same category as quantified phrases, that is, they are terms, and therefore they must have the same type.[30] In fact, if two expressions of the same syntactic category would be assigned two different types, the principle of compositionality would be violated. Accordingly, no expression in natural language is assigned the type e in *PTQ*: Even those expressions that would most naturally seem to denote individual entities (i.e., pronouns and proper names) are actually assigned a higher type.

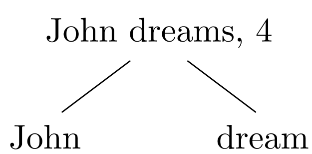
One of the most interesting consequences of the analysis of terms in *PTQ* is that it is possible to provide a uniform formalization of the logical form of the sentences in which they occur, irrespective of whether they contain quantified noun phrases or truly referential terms. As an example, let us consider the case of simple subject-predicate sentences:

(36) a. John dreams.

b. Every man dreams.

Traditionally, these sentences are taken to provide a clear example of the mismatch between linguistic surface form and semantic structure. Although they have the same structure, they are attributed distinct logical forms, $\text{dream}'(j)$ and $\forall x[\text{man}'(x) \to \text{dream}'(x)]$, respectively. This is not any longer so in Montague's *PTQ* where their syntactic analysis is as follows:

(37) a.



b.

Every man dreams, 4

Every man   dream

The syntactic rule that combines a subject term and an intransitive verb (S4) is associated to the following translation rule (T4):

(38) If δ is an expression of category T and β is an expression of category IV, and δ and β translate into an δ' and β' respectively, than $F_4(\delta, \beta)$ translates into $\delta'({}^\wedge\beta')$.

Therefore, the two syntactic trees in (37) give rise to the following parallel translations into expressions of *IL*.

(39) a.

$\text{dream}'(j)\ t$ ${}^\vee{}^\wedge$-elimination

$\Updownarrow$

${}^\vee{}^\wedge\text{dream}'(j)\ t$ λ-conversion

$\Updownarrow$

$\lambda P\, {}^\vee P(j)({}^\wedge\text{dream}')t$

$\lambda P\, {}^\vee P(j)\langle\langle s, \langle e, t\rangle\rangle, t\rangle$ $\text{dream}'\ \langle e, t\rangle$

b.

$\forall x[\text{man}'(x) \rightarrow \text{dream}'(x)]\ t$ ${}^\vee{}^\wedge$-elimination

$\Updownarrow$

$\forall x[\text{man}'(x) \rightarrow {}^\vee{}^\wedge\text{dream}'(x)]\ t$ λ-conversion

$\Updownarrow$

$\lambda P \forall x[\text{man}'(x) \rightarrow {}^\vee P(x)]\ ({}^\wedge\text{dream}')\ t$

$\lambda P \forall x[\text{man}'(x) \rightarrow {}^\vee P(x)]$ $\langle\langle s, \langle e, t\rangle\rangle, t\rangle$ $\text{dream}'\ \langle e, t\rangle$

In both cases, the top node of the tree receives a structurally similar translation, consisting of the functional application of a *IL* expression denoting a set of properties to the property denoting the expression associated to the predicate. The double arrows in (39) show that this formula can be further simplified through the "meaning-preserving" operations of *IL* logic (such as λ-conversion and the ${}^\vee{}^\wedge$-theorem), which produce logically equivalent formulas. The expressions that are usually regarded as exhibiting the logical form of the sentences in (36) then correspond to the result of such simplification. However, notwithstanding the fact that (36a) and (36b) come to be associated with very different expressions of *IL*, they share the same pattern of composition, exhibited by the analysis tree and the step-by-step translation procedure. This also opens the issue of the real status of the notion of logical form in Montague, since prima facie it seems that expressions of *IL* and analysis trees are both plausible candidates to play this role, and as in the case of (39) it can happen that two natural language expressions have the same analysis tree, but they ultimately correspond to different expressions of *IL*. As Partee and Hendriks (1997, 43) argue,[31] actually "the analysis trees are ... the best candidates for a level of 'logical form,' if by 'logical form' one means a structural representation of an expression from which its meaning is transparently derivable." In support of this claim we have to remember that for Montague the level of *IL* is totally dispensable, its role being solely to increase perspicuity (see 6.1).

6.2.2. Intensionality and Meaning Postulates

The existence of nonextensional contexts has attracted the efforts of logicians and philosophers of language from Frege to Carnap, from Quine to Hintikka among many others, who have tried to provide an explanation for this widespread phenomenon of natural language. Nonextensional constructions are typically identified by the failure of the substitutability *salva veritate* of expressions having the same extensions. Among the core examples of nonextensional contexts we find the constructions containing epistemic verbs like *believe* and *know*, modal expressions like the adverb *necessarily*, verbs expressing intention like *look for*, *seek*, and *want*, temporal expressions, and so on. Since Frege, these constructions seem to challenge the universal validity of the principle of extensionality according to which the extension of every expression would depend only on the extension of its components. As we have said, Montague uses intensional logic and structures containing possible worlds and time indexes to provide a compositional semantics of natural language with the goal of accounting for the contexts in which extensionality failures occur. In *MG*, nonextensional contexts are treated as *intensional constructions*, that is, expressions in which the determination of the extension of the whole depends not simply on the extensions of the parts but on the intension of at least one of the parts. Interestingly, in *PTQ* intensionality is taken by Montague to represent the general case, in the sense that, rather than providing a special representation for the expressions giving rise to nonextensional contexts, he treats all basic grammatical relations as intensional, while the subset of extensional expressions is then singled out through meaning postulates. This choice, which is motivated by Montague's overall plan to formulate a translation procedure for an English fragment that has maximum level of generality, is visible in the type-assignment function (34): Every expression belonging to the functional category A/B or $A//B$[32] is assigned as type a function which takes as arguments the intensions of expressions belonging to category A. For instance, the basic expression *believe that* of category IV/S is assigned the type $\langle\langle s,t\rangle,\langle e,t\rangle\rangle$, where $\langle s,t\rangle$ is the type of *propositions*, that is, functions from world-time pairs to truth value. So in *PTQ believe that* is interpreted as a relation between an individual and a proposition,[33] and a sentence like (40a) is translated as (40b):

(40) a. John believes that Mary dreams.

b. $\text{believe}'(j, \,^\wedge\text{dream}'(m))$.

In *PTQ* Montague departs from the tradition and does not regard all intensional constructions as having the form of a propositional operator acting on some implicitly embedded propositional structure. Quine (1960) is a typical example of the received view: He explains the nonextensional character of *John seeks a unicorn* by rephrasing it as *John endeavours that he finds a unicorn.* Although Montague considers *seek* as being equivalent to *try to find*, he nevertheless claims that the intensionality of the former should not be explained by reducing it to the latter. Rather, intensionality is an inherent character of *seek* as a basic transitive expression. In fact, in *PTQ* all transitive verbs, being of category IV/T are assigned the type $f(\text{IV/T}) = \langle\langle s, f(\text{T})\rangle, f(\text{IV})\rangle = \langle\langle s, f(\text{S/IV})\rangle, f(\text{IV})\rangle = \langle\langle s,\langle\langle s,\langle e,t\rangle\rangle,t\rangle\rangle,\langle e,t\rangle\rangle$. Because terms are translated in *PTQ* as expressions of type $\langle\langle s,\langle e,t\rangle\rangle,t\rangle$, that is, sets of properties, then semantically a transitive verb denotes a relation between the intension of a set of properties (i.e., a property of properties or a second-order property) and an individual. This results in the following translation for the sentence *John seeks a unicorn* (in its *de dicto* reading):[34]

(41) $$\text{seek}'(j, \,^\wedge\lambda P\exists x[\text{unicorn}'(x) \wedge \,^\vee P(x)])$$

Similarly, Montague's translation regards as inherently intensional prepositions like *about* (see *John is talking about a unicorn*), intransitive verbs like *raise* or *change* and adverbs like *necessarily* or *allegedly.*

As we said, extensional expressions are captured by Montague by letting a set of formulas of *IL* play the role of *meaning postulates.* The terminology is from Carnap (1952) and their role is to restrict the class of possible models of *IL.* Carnap introduced them to explain analytical relations between lexical items and to overcome the shortcomings of the model of intensions and L-truth formulated in his *Meaning and Necessity* (1947). More generally, meaning postulates have come to be widely used in model-theoretic semantics as a powerful tool to represent relations about words meanings. In fact, one of the main features of Montague's model-theoretic semantics is its *lexical underspecification.* As we saw in 6.1, for Montague interpreting a language amounts to determine the type of reference of the different categories of its expressions. The interpretation procedure consists essentially in assigning, for instance, to the category of intransitive verbs the type of sets of entities, while nothing is said of the way in which specific members of this category, say, *eat* and *run*, differ semantically. Actually, making further distinctions about the semantic content of elements within the same categories is far beyond

Montague's aim, because as Marconi (1997, 10) remarks, he did not need to go any further, "for that was enough to make his point, namely, the availability of a formal method for the construction of a definition of truth for a language that met his own formal and material constraints." In *MG*, meaning postulates are the formal instrument with which finer-grained semantic distinctions within a given category of expressions can be expressed, and lexical properties of words are captured in terms of implications between propositions containing them.

Montague applies the method of meaning postulates to characterize the extensional character of certain expressions of English. For instance, (42) illustrates the postulate introduced in *PTQ* to capture extensional verbs, where S is a variable of type $\langle s, \langle e, \langle e, t\rangle\rangle\rangle$, and X is a variable for the intension of a set of properties:

(42) $\exists S \forall x \forall X(\delta(x, X) \leftrightarrow {}^{\vee}X({}^{\wedge}\lambda y {}^{\vee}S(x, y)))$, where $\delta = \text{love}'$, find', kiss', etc.

This postulate says that although the object of extensional verbs like *kiss*, *love*, and so on is semantically a second-order property, for each of these verbs there is an expression denoting a relation between two entities, to which it is equivalent. For instance, unlike *John seeks a unicorn*, the sentence *John finds a unicorn* implies the existences of unicorns, because the verb *find* is fully extensional:

(43) John finds a unicorn.

To preserve the compositional mapping between syntactic categories and semantic types, *find* is assigned the same type as *seek*, that is, $\langle\langle s, \langle\langle s, \langle e, t\rangle\rangle, t\rangle\rangle, \langle e, t\rangle\rangle$, which gives the flowing translation for (43):

(44) $$\text{find}'(j, {}^{\wedge}\lambda P \exists x[\text{unicorn}'(x) \wedge {}^{\vee}P(x)]).$$

However, since the interpretations of *IL* are restricted to those in which the meaning postulate (42) holds, then there is a relation between individuals, say find* of type $\langle s, \langle e, \langle e, t\rangle\rangle\rangle$, such that (44) is equivalent to (45):

(45) $${}^{\vee\wedge}\lambda P \exists x[\text{unicorn}'(x) \wedge {}^{\vee}P(x)]({}^{\wedge}\lambda y {}^{\vee}\text{find*}(j, y)).$$

Applying the ${}^{\vee\wedge}$-theorem and the λ-conversion, we obtain the logically equivalent (46), which actually means that there is an individual entity such that it is a unicorn and John finds it:

(46) $$\exists x[\text{unicorn}'(x) \wedge {}^{\vee}\text{find*}(j, x)].$$

Other meaning postulates in *PTQ* capture the extensional nature of the preposition *in*; the extensionality of intransitive verbs other than *rise* and *change*; the fact that proper names are rigid designators in the sense of Kripke (1972), that is, they denote the same individual in every possible world; the fact that verbs like *seek*, and *believes that*, which are intensional in their direct object, are nevertheless extensional in their subject position; the truth-conditional equivalence of *seek* and *try to find*, and so on.

Prima facie, meaning postulates provide an alternative to lexical decomposition to capture linguistically relevant aspects of word meaning. In fact, rather than assuming a set of noninterpreted primitive elements, such as the semantic markers in *KF*, meaning postulates allow for expressing inferences between lexical items in a fully model-theoretic fashion. However, introducing a meaning postulate is by itself not less ad hoc than introducing a certain conceptual primitive, and therefore meaning postulates are unable to achieve a real breakthrough with respect to word meaning analysis. In fact, the real challenge, for both meaning postulates and semantic decomposition, lies in the empirical issue of determining which aspects of lexical meaning are systematically relevant in the lexicon and active in affecting the linguistic behavior of lexical items. The problem is thus to motivate in a principled way the adoption of a given postulate or semantic primitive.

6.2.3. The Treatment of Scope

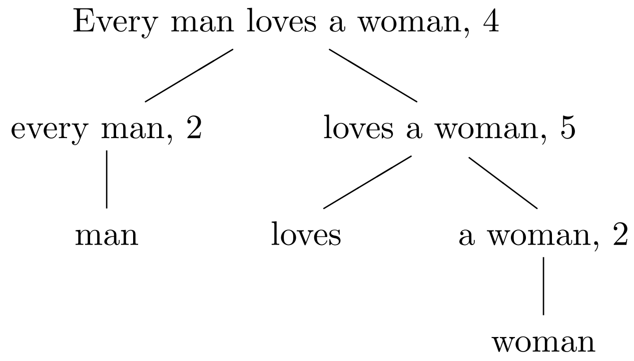
The claim that nonlexical ambiguities are syntactic ambiguities is one of the most important features of *MG*, and is a direct consequences of the principle of compositionality as defined by Montague. Since the syntax-semantics mapping is defined in terms of a homomorphism between algebras, every aspect of semantics that is not related to the interpretation of basic expressions must be traced back to a syntactic opposition. In other terms, every nonlexical ambiguity of a natural language expression must be explained by assigning to it more than one truth-conditionally distinct analysis tree. In fact, the input to semantic interpretation must be provided by a fully disambiguated syntax.

One of the novelties of *PTQ* with respect to the linguistic theory of its time is the way disambiguation is resolved in terms of the order of application of the syntactic rules as encoded in the derivational trees. A typical example is the treatment of *scope ambiguities*, as in the following sentence:

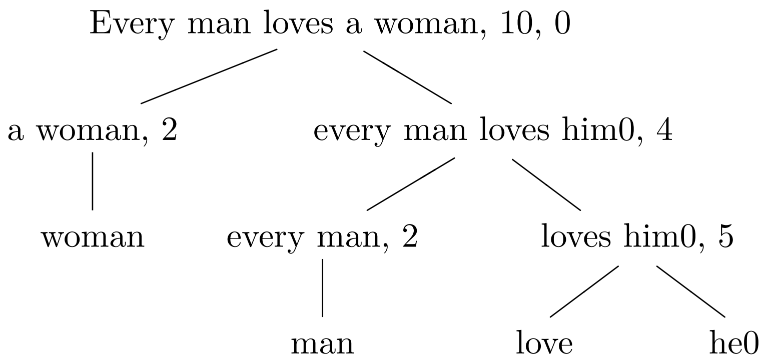
(47) Every man loves a woman.

Montague's ingenious solution to this problem is to see terms as entering syntactic composition "indirectly," through the process of replacement of a free variable in a sentence. As mentioned in 6.2, the category of terms include an infinite set of syntactic variables, he_0, $he_1, \ldots$, which are the only lexical "abstract" (i.e., not corresponding to actual English expressions) elements in *PTQ*. (S14), the most important of the three rules of quantification (also known as the quantifying in rules), combines a term T with a formula,[35] which, unless the rule applies vacuously, must be "open," that is, it contains one or more free variables. In this case, the first occurrence of the variable is replaced with T, and all the other occurrences of the same variable are replaced with an appropriate pronoun. As a consequence, the ambiguity of (47) is traced back to the alternative ways in which the sentence can be derived from its basic expressions, as shown here.

(48) a.



b.



In the translation rule (T14) associated to (S14), first the interpretation of the "open" sentence is lambda-abstracted over the variable, and then the interpretation of the term is applied to the intension of the lambda abstraction:

(49) If α is an expression of category T and φ is an expression of category t, and α and φ translate into an α' and φ' respectively, then $F_{10,n}(\alpha, \varphi)$ translates into $\alpha'(\hat{}\lambda x_n \varphi')$.

Details aside, it can be proved that the top node in the analysis tree (48a) translates into

$$\lambda P \forall x[\text{man}'(x) \to {}^{\vee}P(x)](\hat{}\text{love}'(\lambda Q \exists z[\text{woman}(z) \wedge {}^{\vee}Q(z))]),$$

which after several conversions comes to be logically equivalent to

$$\forall x[\text{man}'(x) \to \exists z[\text{woman}'(z) \wedge \text{love*}(x, z)]]$$

(with love* the extensional variant of love′).

On the other hand, the top node of (48b) translates into

$$\lambda P \exists z[\text{woman}'(z) \wedge {}^{\vee}P(z)](\hat{}\lambda y \forall x[\text{man}'(x) \to \text{love*}(x, y)]),$$

which is logically equivalent to

$$\forall z[\text{woman}'(z) \wedge \forall x[\text{man}'(x) \to \text{love*}(x, z)]],$$

thereby giving the wide scope reading of the existential quantifier.

It is interesting to notice that the function F_{10} in (49) has an index n, ranging over natural numbers. In fact, the rules of quantification are rule schemas such that for every n there is a different rule instantiating them. Consequently, distancing himself from the principle of the autonomy of syntax, Montague claims that each declarative sentence of the fragment he is interested in, has infinitely many analysis trees, which are nevertheless "inessential," exactly because they do not amount to semantic differences. To see this, we have to remember that every term can be either interpreted "in situ" or introduced into a sentence via the rules of quantification and the use of the syntactic variables; in addition, basic expressions contain an infinite number of variables. Therefore, there are an infinite number of analysis trees which are syntactic variants of (48b), that is, they differ only with respect to the pronominal variable he_0. Moreover, there is another possible derivation for (47) on top of (48a) and (48b), one in which the object term *a woman* can also be composed by applying (S14). Similarly, for the sentences *John dreams* and *Every man dreams* the analyses reported in (37) are not the only possible ones. In fact in both cases the subject term can be introduced "indirectly" via the rule (S14). In both cases, the alternative analyses yield interpretations logically equivalent to the given ones.

Montague's analysis of quantification bears a strong resemblance to the one proposed in generative semantics based on the operation of quantifier lowering (section 5). However, it is important to stress that in contrast to generativist semantics, in *MG* quantifier scope is determined *in a purely derivational fashion.* In fact, the analysis tree is not properly to be regarded as a syntactic representational level in the sense of generative grammar, but rather as a way of keeping trace of the process of syntactic composition. Accordingly, the relative scope of quantifiers is defined in terms of the order of their introduction into the analysis tree, and not in terms of the geometry of the tree itself. Nevertheless, the two models gave quickly rise to convergent studies, as witnessed by a number of efforts to stress the synergies between them. For instance, Cooper and Parsons (1976) define a transformational grammar for English equivalent to *PTQ* which is very close to Lakoff's and McCawley's analyses of quantification. Similarly, Dowty (1979) combines *PTQ* with the lexical decomposition approach widely adopted in generative semantics.

Montague's original approach to the logical syntax of natural language has motivated a whole stream of research in model-theoretic semantics, which has widely enlarged Montague's original fragment and has addressed some of the open issues in *PTQ*. Some of the most active areas of application of Montague's method have been the interpretation of pronouns, adverbial quantification, verb aspect, and so on. These developments have often led to major changes in Montague's original solutions. A typical example is the analysis of "donkey sentences" in Kamp (1981), which has been the starting point of one of the most important and influential model-theoretic frameworks of logical semantics, *discourse representation theory*, which radically departs from *PTQ* under many respects. The work of Partee, Heim, Kratzer, and Chierchia among many others also represent important contributions to the logical investigation of natural language stemming from the Montagovian tradition. These have led to important developments of the original framework, while sticking to its spirit.

7. The Problem of Logical Form in Generative Linguistics

As stated in Chomsky (1981, 17), "At the most general level of description, the goal of a grammar is to express the association between representations of form and representations of meaning." In *MG* this association is resolved by defining the algebra of syntax as homomorphic to the algebra of meaning, thereby implementing the general constraint of compositionality to which Montague's system adheres. In the early period of generative linguistics, the form-meaning relation is determined through the Katz–Postal hypothesis, which assigns to deep syntactic structures the whole burden of providing the input to semantic interpretation. As we saw in section 5, generative semantics brings this principle up to the extreme consequence of overthrowing the assumption of the autonomy of syntax itself. The progressive implosion of the generative semantics movement has then run parallel to the exploration of new solutions for the form-meaning relation in grammar, with a twofold goal:

i. Reasserting Chomsky's principle of the autonomy of syntax, and
ii. Improving the grammar so that it can accommodate the phenomena (quantification) that had led generative semanticists to depart from this principle.

In the 1970s, the so-called *extended standard theory* revises the *Aspects* model by abandoning the Katz–Postal hypothesis and by proposing that both deep and surface syntactic structures contribute to the semantic interpretation of sentences (Jackendoff 1972). In particular, the deep structure would be responsible for those aspects of meaning concerning *thematic relations*, while structural aspects like quantification and anaphora would be established at the level of surface structure. Thematic relations include notions like agent, patient, goal, source, and so on and define the semantic roles of predicate arguments. Transformations like the passive do not actually alter these relations. For instance, John is the patient of the killing event in (50a), and does not change this role after the passive transformation:

(50) a. The car killed John.
b. John was killed by the bomb.

On the other side, transformations seem to affect pronominal coreference, and constitute in this way positive evidence for this relation to be marked at the level of the surface structure:

(51) a. John saw himself.
b. *Himself was seen by John.

Under the pressure to find solutions to this kind of phenomena, the generative paradigm underwent its most critical changes since its rising in the 1950s, which led to a huge reorganization of the architecture of grammar. In its early stages, the generative theory of grammar included a set of base phrase structure rules that generated deep structure representations. Then, transformational rules derived surface structure representations by moving some of the constituents, inserting lexical material or deleting some of the elements. Some of the main shortcomings of this model had their roots in the fact that the machinery of transformations was too powerful, the rules too loosely constrained, and they lacked generality. In its new developments, the generative paradigm tries to overcome these shortcomings by adopting a much more general and constrained description of the architecture of language. A new grammatical architecture is now proposed organized around the following modules:

1. A basic module that generates the constituent structures. It includes the principles of *X-bar theory* (Jackendoff 1972), which represents a major generalization and abstraction of phrase structure rules;
2. One single transformation or operation, *Move-α*, which moves elements from one position to another within the phrase markers system generated by the *X-bar* principles;
3. Principles and filters constraining the structures produced by the generative component together with *Move-α*. These principles are organized in several subsystems: bounding theory, government theory, theta-theory, binding theory, Case theory, and control theory.

The new architecture corresponds to the *Government and Binding* (*GB*) approach to the formal study of grammar (Chomsky 1981, 1982, 1986), and represents the mainstream version of the generative paradigm up to the minimalist turn that occurred in the 1990s. In the *GB* model, various syntactic constructions, like passive or relative clauses, are not projected into specific rules of the grammar, but are regarded rather as epiphenomenal distinctions to be analyzed and explained in terms of the interaction of the different principles of the modules of grammar. As a consequence, "The notions 'passive', 'relativization', etc., can be reconstructed as processes of a more general nature, with a functional role in grammar, but they are not 'rules of grammar'." (Chomsky 1981, 7).

One of the most interesting aspects of the *GB* model concerns the relation between syntax and meaning, and the way it has opened new important connections with model-theoretic semantics and with the tradition of logical grammar. The locus of meaning in *GB* depends on two main innovations that characterize this stage of the generative paradigm. The first one is the notion of *trace*, that is, an "empty" syntactic category that appears within syntactic representations as an effect of the application of the rule *Move-α*. In the previous versions of generative grammar, an element which at surface structure had to appear in a different position from the one occupied at deep structure was simply displaced by a specific transformation rule, leaving behind a gap in the original position, as in the case of the interrogative pronoun in (52):

(52) a. you see + PAST what.

b. what did you see.

Here *Move-α* moves a syntactic constituent to a new position in the syntactic representation, but the moved element leaves behind it a trace t coindexed with it:

(53) a. you see + PAST who.

b. who$_i$ did you see t_i.

Traces are syntactic elements voided of any phonological content, but carrying important information: the index of the moved element. According to Chomsky (1976), traces are like variables bound by the syntactic constituent with which they are coindexed.

The appearance of traces in syntactic theory has a number of important consequences. First of all, traces preserve the syntactic and semantic relations that obtained prior to movement. Thus, if in (53a) *who* is the theme argument of the verb, it keeps this role also after it has moved, via the coindexed trace t_i. This fact makes it substantially unnecessary to have both deep and surface structure as input to the semantic component (as assumed by the extended standard theory), since thematic relations are preserved also at surface structure. Second, with traces, syntactic variables appear on the scene of generative linguistics, thereby adding and important element of similarity with Montague's system. Third, the original notion of surface structure now disappears, at least in the way it was understood in the standard theory. In fact, the syntactic representations resulting from applications of *Move-α* contain traces that do not have any phonological content. This is the reason why in *GB* the syntactic representations derived from deep structures via *Move-α* are called *S-structures* (SS), a notational way to indicate they resemble and yet at the same time are distinct from surface structures.

The second major innovation of the *GB* model, closely interrelated with the former, is the appearance of *logical form* (*LF*) as a new and independent layer of syntactic representation, which replaces S-structure as the only interface with the semantic component. One of the main motivations for the introduction of *LF* in the architecture of generative grammar was the need to account for the behavior of interrogative pronouns and quantifiers in natural language which semantically behave as operators binding a variable occurring within their scope. For instance, identifying a question with its possible answers

(Karttunen 1977; Higginbotham 1983), allows for the possibility to take the logical form of (54a) to be (54b):

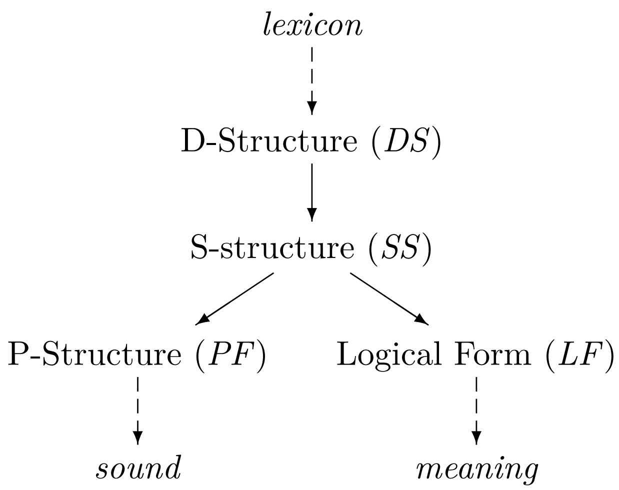
(54) a. Who did you see?
b. For which person x: you saw x.

Once again, this is a move made possible by associating (54a) to the S-structure (53b), making the manipulation mentioned, and then interpreted traces as bound variables. However, since the late 1970s various types of evidence have been brought to show that this could not be the whole story. For instance, in (55a) the pronoun *what* appears in the S-structure in its original position at the end of the clause (in English only one interrogative pronoun is allowed to appear at the left end of the clause). Nevertheless, semantically *what* behaves exactly like *who*, that is, as an operator with its scope over the whole sentence, as showed by (55b), which expresses the *LF* of the sentence:

(55) a. Who saw what?
b. For which person x and thing y: x saw y.

If syntactic representation must display the proper scopes of operators, then it follows that S-structures cannot perform this role. (See Williams 1977 and Fiengo 1977, for similar conclusions.) The conclusion that emerged was that if syntactic representations must provide the proper input to the sound and to the meaning systems, then this input cannot come from the same level of description, because there are elements that are interpreted as if they occurred at a different place from the one in which they are pronounced. This hypothesis has been incorporated into the theory starting from Chomsky and Lasnik (1977) and has a stable place in Chomsky (1981), who adopts the following architecture of grammar (i.e., the “T-model”).

(56)



According to this proposal, each sentence is associated with four levels of *linguistic representation*. Lexical items enter into syntactic representations at *DS* (roughly equivalent to previous deep structures), prior to any transformation. *Move-α* links *DS* to *SS* by moving constituents within phrase markers, and leaving traces in the original place coindexed with the moved element. In addition, *SS* is related, on one hand to *PF* (phonetic form), which represents the interface with the phonological and phonetic component by providing the grammatical information relevant to sound assignment. On the other hand, further applications of *Move-α* generate *LF*, which May (1985, 2) defines as follows:

> [*LF*] represents whatever properties of syntactic form are relevant to semantic interpretation—those aspects of semantic structure which are expressed syntactically. Succinctly, the contribution of grammar to meaning.

LF is the level at which proper scope relations are assigned to operator-like elements (e.g., interrogative pronouns). For example, (55a) would be rendered at *LF* as:

(57) $[_S \text{ what}_j \ [_S \text{ who}_I \ [_S \ t_I \text{ saw } t_j]]]$.

Similarly, May (1977, 1985) proposes that quantificational *NP*s are assigned scope at *LF* through *Quantifier Raising* (*QR*), a particular instance of Move-α that "adjoins" the *NP* to a proper scope position in the phrase marker, typically the S node.[36] For instance, the *SS* of the sentence in (47) (repeated here as (58a)) is presented in (58b). Then two successive applications of *QR* produce two possible *LF* representations (58c) and (58d), depending on their order of application:

(58) a. Every man loves a woman.
b. $[_S \text{ every man } [_{VP} \text{ loves a woman}]]$.
c. $[_S \text{ every man}_I \ [_S \text{ a woman}_j \ [_S t_I \ [_{VP} \text{ loves } t_j]]]]$.
d. $[_S \text{ a woman}_I \ [_S \text{ every man}_j \ [_S t_I \ [_{VP} \text{ loves } t_j]]]]$.

The *scope* of a quantifier (and in general of any expression behaving as a variable-binding operator) is defined as a relation over syntactic representations:

(59) The *scope* of α is the set of nodes that α c-commands at *LF*.

In turn, c-command is defined as follows:[37]

(60) α *c-commands* β if and only if (i) the first branching node dominating α dominates β, and (ii) α does not dominate β.

A trace is bound by α if and only if it is within the scope of α and is coindexed with it. Therefore, in (58c)–(58d), both *NP*s have wider scope over the whole clause, since they c-command it, and the traces left by *QR* are the variables bound by the quantifiers.

In May (1977), this definition of scope also accounts for the structural ambiguity of (58a). Actually, the existence of two interpretations (wide and narrow scope of the existential quantifier) is explained by the fact that (58a) corresponds to two possible *LF*s, the first one in which the universal quantifier has wider scope than the existential one (since it c-commands it) and the second one in which the scope order is reversed. In a later version of his theory of quantification, May revises the definition of scope, by assuming that, given a *LF* of the form $[_S Q_1 [_S Q_2 [_S \ldots]]]$, the operators Q_1 and Q_2 belong to the same Σ-*sequence*. Then, May defines a general *scope principle*, such that the members of a Σ-sequence are free to take any ordering relation (May 1985, 34) Therefore, (58c) and (58d) are both compatible with the narrow and the wide scope interpretation of the existential quantifier, and also with a further reading in which the quantifiers are interpreted independently of one another, that is, as "branching quantifiers."[38]

It is interesting to compare the foregoing treatment of quantification in *GB* with Montague's analysis.

First of all, in *MG* the relative scope of quantifiers is the result of the order of their introduction in the compositional process, that is, the result of the derivational history as shown in the analysis tree (6.2.3). On the other side, according to May, the scope of quantifiers and quantifier-like elements is determined by the particular structure of the representations at the level of *LF*.

Second, Montague defines a rule of *Quantifying in* over terms, a general category including every type of *NP*: proper nouns, syntactic variables, quantificational expressions, and so on. Terms, as we have seen, have the type $\langle\langle s, \langle e, t\rangle\rangle, t\rangle$, and denote sets of properties. Consequently, Montague assigns the same derivation (and thus the same logical form) to *John dreams* and to *Every man dreams* (see (37a,b)), which has the effect that at the interpretive level, both are analyzed as the functional application of the denotation of the subject *NP* to the denotation of the *VP*. On the other hand, the analysis of *NP*s in generative grammar radically departs form such a model. Chomsky (1976, 198) explicitly criticizes Montague for blurring crucial syntactic and semantic differences within the set of *NP*s. Similarly, in May's theory, the two sentences would come to have two distinct *LF* representations:

(61) a. $[_S$ John $[_{VP}$ dreams$]]$.

b. $[_S$ Every man$_I$ $[_S t_I$ $[_{VP} t_I$ dreams$]]]$.

In fact, "at *LF*, quantified and nonquantified phrases are distinguished not only in their interpretation, but in those aspects of their syntax to which the rules of interpretation are sensitive" (May 1985, 25). While for Montague all the *NP*s are alike in their type (and consequently in their syntactic and semantic behavior), *GB* grammarians make a distinction, in the spirit of Frege, between *referential* and *quantificational expressions*. Referential expressions include proper names, pronouns, and in general the traces left by *Move*-α. Quantificational expressions include all the expressions that behave like operators binding variables (i.e., quantifiers, interrogative pronouns, etc.), and whose correct interpretation requires the assignment of scope. Since scope is now defined as a relation over *LF* syntactic representations, one of the consequences of this distinction is that the movement of quantificational expressions at *LF* becomes obligatory in *GB*. This also represents another crucial difference between May's theory of quantification and *MG*: In fact, for Montague the application of the rule *Quantifying in* is optional, and every term can roughly be interpreted "in situ." Conversely, in the *GB* analysis, *NP*s can be interpreted "in situ" (i.e., in the position in which they appear at SS) only if they are referential, while quantificational *NP*s must necessarily move to a position at which they are assigned a scope.

The appearance of *LF* in the generative theory of grammar has brought with it new ways to understand the relationship between formal linguistics, on one side, and model-theoretic semantics and logical grammar on the other:

> LF-Theory and model-theoretic semantics are very similar in some respects. Both are concerned with "structural meaning," abstracting away from word meaning and pragmatics, and both postulate a logical language as the representation of the "structural meaning" of sentences. (Riemsdijk and Williams 1986, 183)

In the early stages of the theory, the dominant semantic paradigm in generative linguistic, *KF* semantics (4.3), was essentially concerned with the explanation of phenomena like analyticity, entailment, synonymy, and so on, in terms of an "internalist" approach to word meanings based on their decomposition into conceptual primitives. *KF* rejected categorically talk of truth-conditions and reference as the ground for any semantic theory aiming to model linguistic competence. The introduction and the growing role of *LF* in the architecture of grammar radically changes this perspective, with the effect of leaving outside the domain of the theory of grammar all the notions that are beyond structural semantics. In particular, one of the goals of the generative enterprise is to study those aspects of meaning—such as scope ambiguities, anaphora—which depend on structural conditions. Moreover, as Riemsdijk and Williams (1986, 188) remark, *LF* basically models the same aspects of meaning represented in a "predicate calculus": "the scope of operators and quantifiers, sameness and distinctness of variables, and predicate-argument structure."

Nevertheless, *LF* differs from Montagovian logical syntax in different respects. First of all, the algebra of syntax in *MG* provides a disambiguated input to interpretation. In contrast, *LF* representations do not need to be semantically unambiguous. For instance, May's scope principle establishes that a *LF* can be totally underspecified with respect to the actual interpretation of the relation between the quantifiers. Second, although *LF* provides the proper structural information for the semantic interpretive component, it is still a layer of syntax, with the same status as *DS* or *SS*. *QR* is actually an instance of *Move-*α, the same movement operation that accounts for the displacement of constituents in passive sentences. As such, *QR* is subject to the same type of constraints that regulate the "overt" movement of constituents. In *MG*, a sentence is assigned those syntactic derivations that are necessary to explain its possible interpretations. In *GB*, a sentence is assigned those *LF* representations that are licensed by the independently motivated principles of grammar. It is therefore an empirical issue whether the principles of universal grammar are able to assign to a given sentence all and only all the *LF* representations that will correspond to its possible structural interpretations. *LF* is in fact a way to reassert the validity and centrality of the principle of the autonomy of syntax.

As a consequence, while Montague pursues his program within the general tradition of logical syntax, the introduction of *LF* in the architecture of grammar opens the way to a wide program that aims to convert logical semantics into syntax: As long as the distribution of linguistic phenomena like quantification, or bound anaphora can be explained on the ground of general, independently motivated principles of syntax, these phenomena can be regarded as part of a theory of syntax. A particularly radical version of this type of approach is given by Hornstein in *Logic as Grammar* (1984, 1):

> semantic theories of meaning for natural language—theories that exploit semantic notions such as "truth," "reference," "object," "property"—are not particularly attractive in explaining what speakers know when they know the meaning of a sentence in their native language. In short a theory of meaning that is viewed as responsive to the same set of concerns characteristic of work in generative grammar to a large extent will not be a semantic theory, ... but instead a syntactic one.

He concludes that "many of the phenomena earlier believed to be semantic ... are better characterized in syntactic terms" (ibid.), where syntactic refers now to the autonomous theory of universal grammar.

Actually, as a layer of syntactic representation *LF* is not directly committed to a particular interpretation. A theory of syntax for Chomsky is supposed to take one up to the point of specifying the structural information relevant for the interpretation of sentences. He does not, strictly speaking, take any position with respect to the nature and form of this interpretation. Although it is the only interface level with the interpretive module, *LF* is in fact an "uninterpreted" level of representation. This leaves the door open to new synergies between the generativist grammar and the truth-conditional semantics. One step in this direction is May (1985) who analyzes quantifiers truth-conditionally as *generalized quantifiers* in the sense of Barwise and Cooper (1981).

Similarly, Higginbotham (1985, 1986, 1989) argues for the possibility of pursuing Davidson's program in semantics by giving a recursive definition of truth for natural language using as input *LF* syntactic representations. We recall that Montague also intended his logical grammar to be a realization of Davidson's program. It then seems that this program is compatible with the principles of the generative enterprise. Chierchia (1995a, 1995b) represents interesting attempts to provide a model-theoretic analysis that pairs *GB* syntactic representations with type-theoretical semantic interpretations in the style of Montague. Both Higginbotham's and Chierchia's works, among many others, are indicative of the new dialectic that characterizes the most recent developments in generative linguistics and in the logical semantics tradition. A few decades ago the principles and methods arising from formal linguistics seemed to be radically orthogonal to the logical investigation of natural language, whereas the intense work and changes on both sides have allowed them to reach important and unprecedented convergences in the inquiry into the universal principles of language.

Notes

1. De Saussure introduced the notion of *phoneme*. As for syntax, he considered it as mostly belonging to *parole*, that is, not to the language as a system, but to language usage.

2. Bloomfield wrote on linguistics in *the International Encyclopaedia of Unified Science* (1939).

3. See our comments at the end of section 2.1.

4. A third level of adequacy is the *descriptive* one, which is intermediate between observative and explanatory adequacy. Descriptive adequacy is defined as follows: "the grammar gives a correct account of the linguistic intuition of the native speaker, and specifies the observed data (in particular) in terms of significant generalizations that express underlying regularities in the language" (Chomsky 1964, 63).

5. For instance, "In fact, the realization that this creative aspect of language is its essential characteristic can be traced back at least to the seventeenth century. Thus we find the Cartesian view that man alone is more than mere automatism, and that its is the possession of true language that is the primary indicator of this" (Chomsky 1964, 51).

6. -*en* is the past participle affix.

7. Some of these are context-sensitive rules, meant to account for the subcategorization properties of lexical items (e.g., V cannot be intransitive if it is followed by a *NP*, etc.)

8. Chomsky (1957), 15.

9. Particularly through the contributions in Fillmore (1968), Gruber (1976), and Jackendoff (1972).

10. The strongest and most definitive attack against the behaviorist view of language is in Chomsky (1959), which critically reviews B. F. Skinner's *Verbal Behavior*.

11. The output of the semantic component is actually formed by the set of readings that the projection rules can derive by all the possible senses that form the dictionary entry of the lexical items (by excluding, at the same time, those combinations that violate semantic selectional constraints).

12. For the chemical theory of concepts, see Coffa (1991).

13. The explicit target of Katz's critique is the definition of the domain of logic in Quine (1955).

14. See for instance Dowty (1979).

15. This characterization of the scope of operators in terms of command will be incorporated in the later stages of the Chomskian framework (see the definition of c-command in section 7).

16. The fuzziness of the notion of meaning adopted by generativist semanticists has also lead them to try to incorporate more and more phenomena within grammar, including presuppositions, speech acts, different sorts of pragmatic phenomena, and so on. Each step was also associated with the posit of more and more abstract deep structures and with the necessity of complex mechanism to derive the surface ones. For a history of this stage, see Newmeyer (1986).

17. "If it were necessary to choose between a categorial base that was convenient for semantics and a non-categorial base that was convenient for transformational syntax, I might still choose the former" (Lewis 1972, 22).

18. "It appears to me that the syntactic analyses of particular fragmentary languages that have been suggested by transformational grammarians, even if successful in correctly characterizing the declarative sentences of those languages, will prove to lack semantic relevance; and I fail to see any great interest in syntax except as a preliminary to semantics" (Montague 1974, 223).

19. See for instance Partee and Hendriks (1997).

20. As Partee and Hendriks (1997, 22) remark, in the rule-by-rule interpretation the homomorphism applies at the level of rules or derivation trees, not at the level of syntactic or semantic operations employed in the rules: "This is frequently a point of confusion.... But it is clear that while there my be a uniform compositional interpretation of the Subject-Predicate combining rule ..., there could not be expected to be a uniform semantic interpretation of a syntactic operation such as concatenation, a syntactic operation which may be common to many rules."

21. This actually amounts to a generalization of the technique employed in *EFL*, where eight semantic domains are individually defined.

22. See Montague (1974, 228, 258).

23. In *UG*, senses are instead the members of $D_{\langle s,a\rangle A,I}$, that is, functions of only one argument, regarded as a possible world.

24. In *PTQ*, quantified terms are introduced syncategorematically, in the sense that there is no syntactic category to which quantifiers and determiners are assigned, and they are rather introduced directly by the syntactic rule forming the term. The same holds true for conjunction and disjunction (see the following).

25. Notice that in *MG* there are only unary functions. Expressions denoting binary relations are of type $\langle e, \langle e, t\rangle\rangle$. The expression $\gamma(\alpha)(\beta)$ is then taken to assert that the objects denoted by β and α stand in the relation denoted by γ. In fact, as is well known, every binary function f from A into $\{1, 0\}$ is equivalent to the function g of type $\langle e, \langle e, t\rangle\rangle$ such that for every $x \in A$, $g(x)$ is the function of type $\langle e, t\rangle$ such that for every $y \in A$, $g(x)(y) = f(y, x)$.

26. It can be shown that for every expression α, $\check{}\hat{}\alpha$ is equivalent to α. However, it is not always the case that α is equivalent to $\hat{}\check{}\alpha$.

27. The argument is attributed by Montague to Barbara Hall Partee.

28. The usefulness of individual concepts has been again advocated from time to time, as for instance in Janssen (1984).

29. Notice also the Russellian treatment of definite descriptions in (35).

30. Montague's analysis is also claimed to have some empirical advantages, since it is then possible to give a straightforward representation of proper nouns when

they appear as elements in a conjunction with some quantified term, as in *John and a student*.

31. For a similar position see Gamut (1991).

32. Others than IV and CN, which are assigned the type $\langle e, t \rangle$, see 6.1.

33. Hintikka (1962, 1968) also analyzes *believe* as a relation between an individual and a proposition, the latter intended as set of possible worlds. Notice that, while for Hintikka (40a) is true if and only if the proposition expressed by the embedded sentence includes the set of the possible worlds *compatible* with John's beliefs, Montague does not set any specific constraint on the type of the relation denoted by *believe that*.

34. Montague's analysis of transitive intensional verbs has been deeply revised, and alternative solutions have been proposed by many scholars. Notice however that the *PTQ* translation of *seek* is actually able to account for interesting semantic properties of this verb. For instance, (41) is able to explain why the fact that John seeks a unicorn does not entail the existence of these animals. In fact, (41) is true even if the set of unicorns is empty in the real world. Moreover, we can also explain why from the fact that neither unicorns nor chimeras exist and that John seeks a unicorn we can not infer that John seeks a chimera. For further details, see Gamut (1991).

35. The other two rules of quantification defined in *PTQ*, (S15) and (S16), combine terms with expressions of category CN and IV, respectively, so that it is possible to quantify also over these types of expressions, besides sentences.

36. Given a constituent β and a node α in a phrase marker, adjoining β to α means to yield either a structure of the form $[_\alpha \beta [_\alpha \ldots]]$ (left adjunction) or a structure of the form $[_\alpha [_\alpha \ldots] \beta]$ (right adjunction).

37. See Reinhart (1976).

38. See Hintikka (1974), Barwise (1979).

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