Part I

The landscape of formal semantics

1

Formal semantics

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1.1 Formal semantics: what is it?

Formal semantics is an approach to semantics, the study of meaning, with roots in logic, the philosophy of language, and linguistics. The word *formal* in "formal semantics" is opposed to *informal* and reflects the influence of logic and mathematics in the rise of scientific approaches to philosophy and to linguistics in the twentieth century. Distinctive characteristics of this approach (see also Pagin, Chapter 3) have been truth conditions as a central part of meaning; (usually) a model-theoretic conception of semantics; and the methodological centrality of the Principle of Compositionality: "The meaning of a whole is a function of the meanings of its parts and their mode of syntactic combination." Most formal semantics is model-theoretic, relating linguistic expressions to model-theoretically constructed semantic values cast in terms of truth, reference, and possible worlds or situations (hence, formal semantics is *not* "formal" in the sense of Hilbert, 1922). And most formal semanticists treat meaning as mind-independent (and abstract), not as concepts "in the head"; formal semanticists distinguish semantics from knowledge of semantics (Lewis, 1975b; Cresswell, 1978).

This sets formal semantics apart from approaches which view semantics as relating a sentence principally to a representation on another linguistic "level" (*logical form*) (May, 1985) or a representation in an innate "language of thought" (Fodor, 1975) or "conceptual representation" (Jackendoff, 1992). The formal semanticist could accept such representations as an aspect of semantics but would insist on asking what the model-theoretic semantic interpretation of the given representation-language is (Lewis, 1970). Kamp's Discourse Representation Theory is an exception, since as noted in Section 1.3.3 below, it includes as essential an intermediate level of representation with claimed psychological reality. Formal semantics is centrally concerned with *compositionality* at the syntax–semantics interface (see Sailer, Chapter 21), how the meanings of larger constituents are built up from the meanings of their parts on the basis of their syntactic structure.

The most important figure in the history of formal semantics was undoubtedly Richard Montague (1930–1971), whose seminal works in this area date from the late 1960s and the beginning of the 1970s. Other important contributors will also be discussed below. Since the 1980s formal semantics has been a core area of linguistic theory; important contributions also continue to come from philosophy, logic, cognitive science, and computational linguistics.

In the last thirty years formal semanticists have become increasingly concerned with issues at the interface between semantics and pragmatics, including context-dependence, information structure, and the semantics/pragmatics of dialogue (see Asher, Chapter 4; Ginzburg, Chapter 5; Schlenker, Chapter 22; Vallduví, Chapter 23). These broadening concerns have led to a range of newer approaches that treat meaning as something more than truth conditions, but still including truth conditions, possibly derivatively, as a central part of what semantics is to capture.

In this chapter we briefly trace the history of formal semantics (Section 1.2) and discuss some of its central principles, debated issues, and divergences within the field (Section 1.3). Since issues concerning the syntax–semantics interface are so crucial to the central working hypothesis of compositionality, we include some brief case studies relating to the syntax–semantics interface in Section 1.4; fuller treatments of related issues will be found in Brasoveanu and Farkas, Chapter 8, and Sailer, Chapter 21. In Section 1.5 we describe the increasing attention to the role of context and to language use and the consequent blending of formal semantics and formal pragmatics (see also Schlenker, Chapter 22). In Section 1.6 we come back to the foundational question of whether meanings are in the head and how formal semantics, which has traditionally rested on the assumption that they are not, connects to cognitive science and studies of language processing and language acquisition. In the final Section 1.7, we mention some of the relatively recent contributions of formal semanticists to issues of language universals and language typology.

1.2 The history of formal semantics

1.2.1 Semantics in linguistics before 1970

Linguistics had partly different beginnings and different emphases in Europe and in America, growing in considerable part out of philological-historical work in Europe and out of that plus anthropological studies in America. Semantics in early linguistics was mainly lexical; lexical semantics and principles of semantic change and semantic drift were important for historical and comparative linguistics. Structuralism arose first in Europe, and de Saussure was influential for structuralism, for putting synchronic grammar into the foreground, and for conceiving of grammar as connecting form and meaning. Bühler's *Sprachtheorie* (1934) included an early treatment of indexicality and perspective shift. Jespersen made lasting contributions to semantics as well as syntax (1924); while in the Netherlands, Evert Beth was laying foundations (1947, 1963) for the cooperation among logicians and linguists that has made the Netherlands one of the major contributors to the development of formal semantics.

Semantics was rather neglected in early and mid-twentieth-century American linguistics, for several reasons. Early American anthropological linguistics depended on fieldwork, where phonetics came first, then phonology, morphology, perhaps a little syntax, and usually no semantics beyond a dictionary. Another reason was the influence of logical positivism and behaviorism: meaning was viewed as an unobservable aspect of language, not fit for scientific study. And the Chomskyan revolution concentrated on syntax: there was much talk of the creativity of language and of language as a window on the mind, but it was all about syntax, investigating finite recursive mechanisms that could characterize the infinite class of sentences of a natural language, and trying to solve the mystery of first-language acquisition.

In 1954, the philosopher Yehoshua Bar-Hillel wrote an article in *Language* (1954) urging cooperation between linguists and logicians and arguing that advances in both fields made the time ripe for combining forces to work on syntax and semantics together. However, Chomsky immediately replied (1955), arguing that the artificial languages invented by logicians were too unlike natural languages for any methods the logicians had developed to have any chance of being useful for developing linguistic theory. Real cooperation of the sort that Bar-Hillel urged began only after Montague's work.

The first efforts to add semantics to Chomsky's generative grammar were made by Katz and Fodor (1963), who were the first to use the term *compositionality* (although in most of their work they speak rather of *projection rules*), proposing rules that first interpret underlying phrase-markers, bottom-up, and then interpret the result of applying transformations. A little later Katz and Postal (1964) proposed that all semantically relevant information

should actually be contained in the underlying phrase-markers and that transformations should preserve meaning. The Katz–Postal hypothesis was adopted in Chomsky (1965) as part of what Chomsky later dubbed "the standard theory," with Deep Structure as the input to semantics.

But very soon the "discovery" of quantifiers spoiled the illusion of meaning-preservingness for many transformations; I illustrate with a few key examples without giving the rules or the structures. In each case the (a) example illustrates the apparently meaning-preserving transformation when the NPs are proper names, but in the (b) example, application of the same rule does not preserve meaning. We will come back to some of these examples in discussing the syntax–semantics interface in formal semantics.

(1) a. John wants John to win $\Longrightarrow$ John wants to win
b. Everyone wants everyone to win $\Longrightarrow$ [!?] Everyone wants to win

(2) a. John voted for John $\Longrightarrow$ John voted for himself
b. Every candidate voted for every candidate $\Longrightarrow$ [!?] Every candidate voted for himself

(3) a. Three is even or three is odd $\Longrightarrow$ Three is even or odd
b. Every number is even or every number is odd $\Longrightarrow$ [!?] Every number is even or odd

The discovery that quantifiers, negation, and conjunctions were not properly interpretable at the level of Deep Structure as conceived in 1965 was one important factor in the genesis of the "Linguistic Wars". Generative Semanticists (Lakoff, McCawley, Ross, and others, cf., Huck and Goldsmith, 1995) responded by making Deep Structure "deeper", closer to "logical form", which for linguists then meant more closely resembling first-order predicate logic. Interpretive Semanticists (Jackendoff, Chomsky) kept the syntax closer to the "standard theory" and added additional interpretive mechanisms at various syntactic levels.

During all this time, the notion of semantic interpretation was in a rather primitive state. Katz, Fodor, and Postal worked with "semantic markers" modeled on phonological distinctive features, treating sentence meanings as bundles of semantic markers. The Generative Semanticists added first-order logic and uninterpreted but supposedly universal predicates and operators such as "CAUSE" and "BECOME". The reaction of philosophers of language was most notably formulated by David Lewis (1970).

> But we can know the Markerese translation of an English sentence without knowing the first thing about the meaning of the English sentence: namely, the conditions under which it would be true. Semantics with no treatment of truth conditions is not semantics. (Lewis, 1970, p. 1)

To linguists, concern with *truth* looked puzzling. Linguists were trying to figure out mental representations that could underlie linguistic competence.

"Actual truth" was (correctly) considered irrelevant, and truth *conditions* were not understood or appreciated.

1.2.2 Semantics in logic and philosophy before 1970

In the meantime great progress was made in semantics in logic and philosophy of language. The greatest foundational figure for formal semantics is Gottlob Frege (1848–1925). He made crucial advances to the analysis of variables and quantifiers, and introduced the distinction between *Sinn* and *Bedeutung*, sense and reference, the precursor of the modern intension–extension distinction. Frege is also credited with the Principle of Compositionality,[1] a cornerstone of formal semantics, and a principle quite universally followed in the design of the formal languages of logic, with a few interesting exceptions.[2]

> The Principle of Compositionality: the meaning of a complex expression is a function of the meanings of its parts and of the way they are syntactically combined.

Further advances were made by Russell, Carnap, and others. Wittgenstein (1922) first articulated the idea that "To know the meaning of a sentence is to know what is the case if it is true" (*Tractatus*, 4.024). Tarski (1902–1983) formalized *model theory* inside set theory and provided the first formal model-theoretic semantics for logical languages (Tarski, 1944; Feferman and Feferman, 2004); his goals concerned metalogic and the avoidance of semantic paradoxes, not semantics itself (Etchemendy, 1988).

Around that time, there was a major dispute within philosophy, the "Ordinary Language" vs. "Formal Language" war, concerning the role of natural language in philosophical argumentation, including the question of whether the analysis of natural language could be a source of philosophical insights, or whether natural language was too unruly and needed to be replaced by a suitably constructed formal language for purposes of exact argumentation. The Ordinary Language philosophers, including late Wittgenstein, Austin, Ryle, and Strawson, were a new generation who rejected the formal approach and urged closer attention to the functions of ordinary language and its uses, including much more attention to language in context, i.e., to pragmatics. In his critique of Russell in "On Referring", Strawson (1950) said, "Neither Aristotelian nor Russellian rules give the exact logic of any expression of ordinary language; for ordinary language has no exact logic." Russell rejected Strawson's critique, but added "I agree, however, with Mr. Strawson's statement that ordinary language has no logic" (1957). It is noteworthy that both sides in this "war" (as well as

[1] Not without some controversy; see Janssen (1983). And see Hodges (2001) for a discussion of the relation between compositionality and contextuality in Frege, and Pelletier (2001) for a third evaluation.

[2] It has been observed in a number of works (I learned it from Tarski, p.c., 1971) that the usual semantics for the quantifiers of first-order logic in terms of satisfaction and assignments is not strictly compositional.

Chomsky) were in agreement that logical methods of formal language analysis did not apply to natural languages.

The response of some formally oriented philosophers was to try to analyze ordinary language better, including its context-dependent features. Within philosophical logic, the foundational work of Frege, Carnap, and Tarski had led to a flowering of work on modal logic and on tense logic, on conditionals, on referential opacity, and on other philosophically interesting natural language phenomena. Quine had rejected modal and intensional notions as incurably unclear, but Kripke (1959), Kanger (1957a,b), and Hintikka (1962) revolutionized the field by providing a model-theoretic possible-worlds semantics for modal logic. And first Reichenbach (1947) and then Prior (1967) made great progress on the development of the logic of tenses, a notorious source of context-dependence in natural languages; Thomason (1996) identifies Prior as an important contributor to "natural language semantics logicism".

Paul Grice (1913–1988) contributed in a quite different way to the eventual resolution of the war. His work on conversational implicatures (Grice, 1975) showed that explanatory pragmatic principles can allow semantics to be simpler, so that the apparent gap between the "logicians' meaning," even in terms of standard, extensional first-order logic, of words like *the* and *if* and *or* and their ordinary-language meaning might be much less than had been supposed. And although not all of his proposals for the semantics of such words have survived, his methodological lesson and his pragmatic principles became highly influential for formal and informal semantics alike. Once his lessons sunk in, it became obligatory in studying semantics to also think about pragmatics, although whether and how pragmatics "belongs in the grammar" has remained controversial for decades (Horn, 2006).

1.2.3 Montague's work

Montague had been an important contributor to these developments in philosophical logic. Montague was a student of Tarski's, and at UCLA was a teacher and then a colleague of David Kaplan, co-authored a logic textbook with his colleague Donald Kalish, and was an active part of a strong logic group. As a logician, Montague built on the Frege–Tarski–Carnap tradition of model-theoretic semantics of logic and developed an intensional logic with a rich type theory and a possible-worlds model-theoretic semantics, incorporating certain aspects of "formal pragmatics", including the treatment of "indexical" words and morphemes like *I, you* and the present tense (Montague, 1968, 1970b). This was accomplished in part by treating both worlds and times as components of "indices", then generalizing from times to "points of reference", that is, complexes of relevant features of contexts, and treating intensions as functions from indices (not just possible worlds) to extensions. He generalized intensional notions such as property, proposition, individual concept, into a fully typed intensional logic, extending the

work of Church (1951), Carnap (1956), and Kaplan (1964), putting together the function-argument structure common to type theories since Russell with the treatment of intensions as functions from indices to extensions.

In the late 1960s, Montague turned to the project of "universal grammar", which for him meant a theory of syntax and semantics encompassing both formal and natural languages, a groundbreaking project that became *Montague Grammar*,[3] and to which his last three papers were devoted, with plans for a book-length treatment interrupted by his untimely death in 1971.

That project evidently grew out of his work on the development of a higher-order typed intensional language suitable for doing philosophy. His paper "On the Nature of Certain Philosophical Entities" (NCPE) (Montague, 1969) contains a great deal that can be considered as much a matter of semantics as of philosophy, and foreshadows some of his work in his three final "language" papers. An important passage in that paper with respect to Montague's program occurs on pages 154–156, explaining his change from believing that philosophy should be done in the framework of set theory to believing that it should be done in the framework of intensional logic, and announcing his claim that he has constructed an adequate intensional logic.

> One system of intensional logic now exists which fully meets the objections of Quine and others, which possesses a simple structure as well as a close conformity to ordinary language, and concerning the adequacy of which I believe no serious doubts can be entertained. (Montague, 1969, p. 156)

This big "framework" change in Montague's approach to logic and philosophy is described and discussed in Cocchiarella (1981).

His attitude toward his work on natural language was ambivalent. On the one hand, he considered it worthwhile to demonstrate that "The syntax and semantics of certain not insignificant fragments of English can be treated just as formally and precisely as those of the first-order predicate calculus, and in very much the same manner" (Montague, in Staal, 1969, p. 274). However, at the same time, he asserted that "it would appear more important to extend the scope of constructed systems than to discover the exact rules of natural languages" (Staal, 1969, p. 275). As Thomason (1996) notes, Montague's quest for a "formal philosophy" grounded on his intensional logic remains unfulfilled and possibly quixotic, and his legacy is ironically rather in the "rather easy and not very important"[4] project of the analysis of ordinary language.

[3] The term entered the Oxford English Dictionary in 2002, the first citation being to Rodman (1972), a collection of papers by participants in a seminar taught at UCLA by the author.

[4] This unpublished quotation from Montague's notes, as well as evidence that Montague might have later revised his "rather easy" assessment, is discussed in Partee (2011, 2013).

Montague's work on the formal treatment of natural languages is all in his last three papers, "English as Formal Language" (EFL) (1970a), "Universal Grammar" (UG) (1970b), and "The Proper Treatment of Quantification in Ordinary English" (PTQ) (1973b). The one that had the most impact on linguists and on the subsequent development of formal semantics was PTQ: short, but densely packed (see Partee, 1975, 1997b; Janssen, 1994). Montague Grammar has often meant what Montague did in the fragment in PTQ and the extensions of PTQ by linguists and philosophers in the 1970s and 1980s. But it is the broader algebraic framework of UG that constitutes Montague's theory of grammar.

Before Montague, linguists took as the task of semantics the explication of ambiguity, semantic anomaly, and synonymy: the key questions were how many readings a sentence has, and which sentences share readings. The individuation of "readings" had always been problematic, though, and there was often crucial disagreement about data. Intuitions about "readings" undoubtedly rested in part on judgments concerning truth conditions, but truth conditions were never explicitly discussed. The methods used in early linguistic semantics primarily involved lexical decomposition in terms of *semantic features*, plus hypothesized abstract tree structures displaying scope relations and other aspects of *semantic structure*. The introduction of truth conditions as the basic semantic property of a sentence that a semantic theory should capture profoundly affected the adequacy criteria for semantics and led to a great expansion of semantic research.

Montague's (1970) paper, UG, contains the most general statement of Montague's formal framework for the description of language. The central idea is that anything that should count as a grammar should be able to be cast in the following form: the syntax is an algebra, the semantics is an algebra, and there is a homomorphism mapping elements of the syntactic algebra onto elements of the semantic algebra. In the PTQ grammar for a fragment of English, the syntax is not explicitly presented as an algebra, but if it were transformed into one, the elements would be the analysis trees.

The choice for the semantic elements is totally free, as long as they make up an algebra. The semantic elements, or *semantic values* as they are often called, could be taken to be the model-theoretic constructs of possible-worlds semantics as in Montague's fragments of English and most "classical" formal semantics, or the file change potentials of (Heim, 1982), or the game strategies of game-theoretical semantics, or the simple extensional domains of first-order logic, or hypothesized psychological concepts, or expressions in a "language of thought", or anything else; what is constrained is not the "substance" of the semantics but some properties of its structure and of its relation to syntactic structure. It is the homomorphism requirement, which is in effect the compositionality requirement, that provides the most important constraint on UG in Montague's sense, and it is therefore appropriate that compositionality is frequently at the heart of controversies concerning formal semantics.

Stokhof (2006) summarizes two important characteristics of Montague's theory as defined in UG and illustrated in PTQ:

a. Semantics is syntax-driven, syntax is semantically motivated. (Compositionality)
b. Semantics is model-theoretic.

A methodological principle implicit in Chomskyan syntax in the 1960s, encouraged although not required by the Katz–Postal hypothesis that meaning is determined at Deep Structure, and carried to extremes in Generative Semantics, was the principle that sameness of meaning should be reflected in sameness of syntactic Deep Structure. However, from the perspective of Montague Grammar, sameness of meaning does not require identity at any syntactic level (see Thomason, 1976): semantics is model-theoretic, not representational, not "syntactic".

In formal semantics, the core of sameness of meaning is sameness of truth conditions; and it does not require sameness on any syntactic level for two sentences to end up having the same truth conditions. Thus, formal semantics removed much of the motivation for that aspect of Generative Semantics. Its semantic goals could apparently be met, even exceeded, in a formal semantic approach, offering greater explicitness and compatible with more "conservative", less abstract, syntax. Thus, the rise of Montague Grammar was one factor in the decline of Generative Semantics and the fading away of the linguistic wars.

Details of Montague's analyses have in many cases been superseded, but in overall impact, PTQ was as profound for semantics as Chomsky's *Syntactic Structures* was for syntax. Emmon Bach (1989, p. 8) summed up their cumulative innovations thus: Chomsky's Thesis was that English can be described as a formal system; Montague's Thesis was that English can be described as an *interpreted* formal system.

1.2.4 Other contemporaneous work

While Montague clearly occupies a preeminent position in the history of formal semantics, he did not work in a vacuum. Works that influenced his thinking, as evidenced in his papers and in his seminars from 1967 and later, include, among others, Quine (1960b), Geach (1962, 1967) for puzzles of intensionality; Frege (1892b), Davidson (1965, 1967a, 1970), Kripke (1963), and various works of and/or conversations with Alfred Tarski, David Lewis, David Kaplan, Dana Scott, Rudolf Carnap, Alonzo Church, Yehoshua Bar-Hillel, J. F. Staal, Terence Parsons, and Barbara Partee, and several of his students including Hans Kamp, Dan Gallin, and Michael Bennett.

Independently, on the other side of the country, Donald Davidson and Gil Harman were both at Princeton from 1967 to 1969, interacting intensely, optimistic about the potential fruitfulness of linguistics–philosophy interactions and about the prospects of Generative Semantics, with its underlying