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The Development of Formal Semantics in Linguistic Theory

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1. Earlier traditions in semantics.

Formal semantics has roots in several disciplines, most importantly logic, philosophy, and linguistics. The most important figure in its history was Richard Montague, a logician and philosopher whose seminal works in this area date from the late 1960's and the beginning of the 1970's; its subsequent development has been a story of fruitful interdisciplinary collaboration among linguists, philosophers, logicians, and others, and by now formal semantics can be pursued entirely within linguistics as well as in various interdisciplinary settings.

At the time of Montague's work, semantics had been a lively and controversial field of research for centuries, and radically different approaches to it could be found across various disciplines. One source of deep differences was (and still is) the selection of the object of study: the central questions of semantics may come out quite differently if one focusses on language and thought, or on language and communication, on language and truth, or on language "structure" per se. A more accidental but no less profound source of differences is the research methodology prevalent in the field within which one approaches questions of semantics. Thus early generative linguists concentrated first on "semantic features", using methodology influenced by phonology to study questions of lexical meaning borrowed in part from psychology (which emphasized concept discrimination and principles for scaling semantic fields) and structuralist anthropology; a central goal in such approaches to lexical semantics was and still is to identify semantic "distinctive features" or semantic "atoms" which combine to form lexical meanings, with never-ending debates about whether total decomposability into such atoms is possible at all and about the universality or non-universality of the "semantic primitives" of natural languages. The increasingly dominant impact of syntax on the whole field soon led to focus on questions such as the relation between syntactic and semantic ambiguity, the issue of whether transformations preserve meaning, and other such structural questions which can be explored relatively independently of the issue of "what meanings are;" semantic representations were often modelled on syntactic tree structures (sometimes influenced by the syntax of some logic), and in some theories were (and are) taken to be identical with some level of syntactic structures (e.g., the underlying structures of Generative Semantics or the level of Logical Form of GB syntax.)

In the first years of generative grammar, the key semantic properties of sentences were taken to be ambiguity, anomaly, and synonymy, analyzed in terms of how many readings a given sentence has, and which sentences share which readings (Katz and Fodor (1963), Chomsky (1965)). The impact of philosophy and logic on semantics in linguistic work of the 50's and 60's was limited; many linguists knew some first-order logic, aspects of which began to be borrowed into linguists' "semantic representations," and there was gradually increasing awareness of the work of some philosophers of language [[FN1]]. Generative semanticists in the late 1960's and early 1970's in particular started giving serious attention to issues of "logical form" in relation to

grammar, and to propose ever more abstract underlying representations inte. to serve simultaneously as unambiguous semantic representations and as input to the transformational mapping from meaning to surface form (see, for instance, Bach 1968, Fillmore 1968, Karttunen 1969, Lakoff 1968, 1971, 1972). But these semantic representations were generally not suggested to be in need of further interpretation, and truth-conditions and entailment relations were never explicitly mentioned as an object of study in the indigenously linguistic traditions that existed before formal semantics came into linguistics in the 1970's.

The truth-conditional tradition in semantics has its source in the work of those logicians and philosophers of language who viewed semantics as the study of the relation between language on the one hand and whatever language is *about* on the other, some domain of interpretation which might be the real world or a part of it, or a hypothesized model of it, or might be some constructed model in the case of an artificial language. Such philosophers and logicians, at least since Frege, have tended strongly to view semantics non-psychologistically, making a distinction between language and our knowledge of it, and generally taking such notions as reference, truth-conditions, and entailment relations as principal data a semantic description has to get right to reach even the most minimal standards of adequacy.

Before Montague, most logicians and most linguists (with important exceptions such as Reichenbach 1947) had been agreed, for different reasons, that the apparatus developed by logicians for the syntax and semantics of formal languages was inapplicable to the analysis of natural languages. Logicians considered natural languages too unsystematic, too full of vagueness, ambiguity, and irrelevant syntactic idiosyncracies to be amenable to formalization. Those linguists who took note of logicians' formalizations of the syntax and semantics of formal languages tended to reject the logicians' approach for either or both of two reasons: (i) the formal languages invented and studied by the logicians appeared to be structurally so different from any natural language as to fall outside the bounds of the class of possible human languages and hence to be irrelevant to linguistics [[FN2]], or (ii) logicians generally eschewed the concern for psychological reality which is so important to most linguists; not only is this difference noticeable in what the notion of "possible language" means to a logician vs. a linguist, but also in the question of whether properties like truth conditions and entailment relations are or are not relevant to linguistics, given that speakers of a natural language do not always (in fact cannot always) have reliable intuitions about them.

2. Montague and "English as a Formal Language".

2.1. The rise of model-theoretic semantics in philosophy and logic

Within philosophical logic, the foundational work of Frege, Carnap and Tarski led to a flowering in the middle third of this century of work on modal logic and on tense logic, on conditionals, on referential opacity, and on the analysis of other philosophically interesting natural language phenomena. The competition among different modal logics characterized by different axiom systems had led some philosophers like Quine to reject modal and intensional notions as incurably unclear; but the field was revolutionized when Kripke (1959) and Kanger (1957a,b) argued for the importance of distinguishing between possible models of a language (the basis for the semantical definition of entailment) and possible worlds (possible states of affairs, different ways things might be or might have been) as elements that should be included within

a given model to be used in giving a model-theoretic semantics for modal notions.[[FN3]] The distinction between models and worlds is an important one for the semantics of all intensional constructions, but one that is still not always clearly appreciated; see discussion in Gamut (1991, Chapter 2). (The distinction between moments or intervals of time and models is intuitively much clearer, so it can be helpful to recall the analogy between the role of times in models of tensed languages and the role of possible worlds in models of modal languages, an analogy noted below as one of Montague's contributions to the field.)

The resulting extension of model-theoretic techniques into the realm of modal logic led to a great expansion of work in logic and the philosophy of language in quantified modal logic, tense logic, the logic of indexicals and demonstratives, studies of adjectives and adverbs, propositional attitude verbs, conditional sentences, and intensionality more generally. With few exceptions, most of this work followed the earlier tradition of not formalizing the relation between the natural language constructions being studied and their logico-semantic analyses: the philosopher-analyst served as a bilingual speaker of both English and the formal language used for analysis; only the formal language would be provided with a model-theoretic semantics.

2.2 Montague

Montague was himself an important contributor to these developments in philosophical logic. Montague had been a student of Tarski's (along with Dana Scott, with whom he corresponded while working out his intensional logic), and as a faculty member 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 spanning the departments of Philosophy and Mathematics. He did important work on intensional logic, including the unification of tense logic and modal logic and more generally the unification of "formal pragmatics" with intensional logic (Montague 1968, 1969a.) This was accomplished in part by treating both worlds and times as components of "indices" and intensions as functions from indices (not just possible worlds) to extensions. He also generalized the intensional notions of property, proposition, individual concept, etc., into a fully typed intensional logic, extending the work of Carnap (1956), Church (1951), and Kaplan (1964), putting together the function-argument structure common to type theories since Russell with the treatment of intensions as functions to extensions [[FN4]].

Although linguists have focussed on Montague's last three papers, and it is those that most directly set the framework for formal semantics, a considerable amount of Montague's earlier work was on areas of philosophical logic of direct relevance to issues in semantics and on the logico-philosophical analysis of various concepts that have traditionally been of concern in the philosophy of language: the logic of knowledge and belief, the interpretation of embedded that-clauses, syntactic vs. semantic analysis of modal operators, the analysis of events as properties of moments of time, and the analysis of obligations and other "philosophical entities" discussed in Montague (1969) [NCPE]. It was reportedly [[FN5]] the experience of co-authoring Kalish and Montague (1964), a logic textbook, that gave Montague the idea that English should after all be amenable to the same kind of formal treatment as the formal languages of logic. Kalish and Montague took pains to give students explicit guidance in the process of translation from English to first-order logic: rather than the usual informal explanations and examples, they produced an algorithm for step-by-step conversion of sentences of (a subset of) English into formulas of first-order logic. Montague reportedly

then reasoned that if translation from English into logic could be formalized, it must also be possible to formalize the syntax and semantics of English directly, without proceeding via an intermediate logical language. This led to the provocatively titled paper "English as a Formal Language" (Montague 1970b) [EFL], which begins with the famous sentence, "I reject the contention that an important theoretical difference exists between formal and natural languages."(p.188 in Montague 1974.) As noted by Bach (1989), the term "theoretical" here must be understood from a logician's perspective and not from a linguist's. What Montague was denying was the logicians' and philosophers' common belief that natural languages were too unruly to be amenable to formalization; what he was proposing, in this paper and even more systematically in Montague (1970c), was a framework for describing syntax and semantics and the relation between them that he considered compatible with existing practice for formal languages and an improvement on existing practice for the description of natural language. The central properties of this framework are the subject of the next subsection.

2.3. Montague's theory of grammar.

Montague's paper "Universal Grammar" (Montague 1970c) [UG] contains the most general statement of Montague's formal framework for the description of language. [[FN6]] [[FN7]]. 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. This very general definition leaves a great deal of freedom as to what sorts of things the elements and the operations of these algebras are. As for the syntactic algebra, in the case of a typical logical language the elements can be the well-formed expressions, but in the case of a natural language, ambiguity makes that impossible, since the homomorphism requirement means that each element of the syntactic algebra must be mapped onto a unique element of the semantic algebra [[FN8]] (the shorthand terminology for this is that the syntax must provide a "disambiguated language"). 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 relation between a linguist's syntactic component and syntax as an algebra is not always easy to see, and it can be non-trivial to determine whether and how a given syntax can be presented as an algebra, and more particularly, as an algebra homomorphic to a corresponding semantic algebra. The core issue is compositionality, since for Montague, the central function of syntax is not simply to generate the well-formed expressions of a language but to do so in such as way as to provide the necessary structural basis for their semantic interpretation. [[FN9]]] GPSG and the various categorial grammar frameworks currently under exploration are among the clearest examples of "linguists' grammars" that are more or less consistent with the requirements of Montague's UG, since context-free grammars are easily converted to equivalent algebras (their surface phrase-structure trees being isomorphic to their derivation trees.)

The choice for the semantic elements is totally free, as long as they make up an algebra, i.e. as long as there is a well-defined set of elements and well-defined operations that have elements of the algebra as operands and values. 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; see section 3.5. below.

"Universal Grammar" presents formal frameworks for both "direct" and "indirect" semantic interpretation, the latter proceeding via translation into an intermediate language, as in Montague's grammars for fragments of English in UG and PTQ; only in his EFL fragment did he provide a direct model-theoretic interpretation of the natural language syntactic rules. (Examples of direct interpretation can also be found in the work of Cresswell, von Stechow, and Kratzer.) For "indirect" semantic interpretation, the notion of compositional translation is defined; as expected, this involves a requirement of homomorphism between two syntactic algebras; the process is therefore iterable and any number of intermediate languages could be invoked (see the application of this idea in Rosetta (1994).) When both translation into an intermediate language and the semantic interpretation of that intermediate language are compositional, the intermediate language is in principle dispensable, since the composition of those two homomorphisms amounts to a direct compositional interpretation of the original language. Montague viewed the use of an intermediate language as motivated by increased perspicuity in presentation; linguists with a Chomskyan background tend to be interested in the psychological reality of some level of "semantic representation", but direct evidence for or against such levels has been scarce.

The paper of Montague's that had the most impact on linguists was "PTQ" (Montague 1973), and to many linguists, "Montague Grammar" has probably meant what Montague did in PTQ (and what subsequent linguists and philosophers did following the model of PTQ with greater and lesser innovations; the term therefore has a vague boundary with the broader term "formal semantics"), although it is the broader algebraic framework of UG that constitutes Montague's theory of grammar. Properties of PTQ that are not required by UG include the use of a version of categorial grammar in the syntax; the use of the lambda-calculus, an extremely important [[FN10]] tool for helping to make compositionality realizable; Montague's IL (Intensional Logic) as an intermediate language (with its particular possible-worlds interpretation of propositions, properties, etc); function-argument application as the interpretation of virtually all basic grammatical relations; the exclusive use of unary functions and concomitant use of strictly binary-branching (where branching at all) analysis trees; the introduction of individual concepts [[FN11]]; the very important and influential analysis of noun phrases as uniformly denoting generalized quantifiers [[FN12]], about which more will be said below; a particular treatment of quantifier scope, of de dicto and de re readings of NPs in opaque contexts, and of pronouns as bound variables (embodying Montague's solution to important problems about quantifiying into opaque contexts raised by Quine (1960)); and the generalizing of virtually all argument-taking expressions to "intensional versions", part of the strategy illustrated in PTQ of "generalizing to the worst case" in order to achieve uniformity of semantic type for each syntactic category. I have just summarized key properties of PTQ at breakneck speed in an extremely

abbreviated form; pedagogical introductions and fuller discussions are readily available elsewhere (e.g. Partee (1973b, 1975a), Thomason (1974), Dowty et al (1981), Link (1979), Gamut (1991); see Zimmermann (1981) for an insightful review of three German Montague grammar textbooks including Link (1979).)

One important principle required by the UG framework and at the heart of Montague's semantics, inherited from the traditions of logic and model theory and transmitted as one of the defining principles of formal semantics, is the principle that truth-conditions and entailment relations are the basic semantic data, the phenomena that have to be accounted for to reach observational adequacy. Cresswell (1978) has put this in the form of his "Most Certain Principle": we may not know what meanings are, but we know that if two sentences are such that we can imagine a situation in which one of them is true and the other false, then they do not have the same meaning. (Cresswell shows how many decisions about semantic analysis, both in general architecture and in particular instances, can be seen to follow from that principle.) The adoption of truth conditions and entailment relations as basic semantic data is not innocuous from a foundational perspective (see section 3.2). Nevertheless it has proved so helpful in making semantic proposals more explicit than they had previously been that it has become widely (although not universally) adopted, especially but not only among formal semanticists. It may be hard to remember or realize how surprising and controversial an idea it was to linguists in the early 1970's.

Another interesting feature of Montague's work which was novel to linguists and became quite influential methodologically was the "method of fragments"; "fragment" has become almost a technical term of formal semantics. What is meant is simply writing a complete syntax and semantics for a limited subset ("fragment") of a language, rather than, say, writing rules for the syntax and semantics of relative clauses or some other construction of interest while making implicit assumptions about the grammar of the rest of the language. Linguists have traditionally given small (but interesting) fragments of analyses of various aspects of complete natural languages; Montague gave complete analyses of small (but interesting) fragments of natural languages. [[FN13]]

Montague did not work single-handedly or in a vacuum; his papers include acknowledgements to suggestions from David Lewis, David Kaplan, Dana Scott, Rudolph Carnap, Alonzo Church, Terence Parsons, Hans Kamp, Dan Gallin, the author, and others. And there were other important early contributors to the development of formal semantics as well, several of whom have been mentioned and/or will be mentioned in Section 3 below.

3. "Montague Grammar" and linguistics.

3.1. The introduction of Montague's work into linguistics.

Montague was doing his work on natural language at the height of the "linguistic wars" between generative and interpretive semantics (see Fodor (1980), Newmeyer (1980), Harris (1993)), though Montague and the semanticists in linguistics had no awareness of one another. (Montague was aware of Chomsky's work and respected its aim for rigor but was skeptical about the fruitfulness of studying syntax in isolation from semantics (see Note 9, section 2.3).) As argued in Partee (1973b, 1975a), one of the potential attractions of Montague's work for linguistics was that it offered an interestingly different view of the relation between syntax and semantics that might be able to accommodate the best aspects of both of the warring approaches. The PTQ instantiation of Montague's algebraic theory illustrates

what Bach (1976) christened the "rule-by-rule" approach to syntax-semantics correspondence: syntactic rules put expressions (or expressions-cum-structures, see Partee 1975a) together to form more complex expressions, and corresponding semantic rules interpret the whole as a function of the interpretations of the corresponding parts. This is quite different from both generative and interpretive semantics, which were framed in terms of the prevailing conception of syntactic derivations from some kind of phrase-structure-generated underlying structures via transformations to surface structures, with the debate centered on which level(s) of syntactic representations provided the basis for semantic interpretation. The closest linguistic analog to Montague's rule-by-rule approach was in Katz and Fodor's (1963) proposal for compositional interpretation of Chomsky's T-markers (deep structure P-markers plus transformational history), but that approach was abandoned as too unrestrictive once Katz and Postal (1964) had introduced the hypothesis that transformations might be meaning-preserving, a hypothesis that in a sense defines generative semantics. Interpretive semantics did not go back to the derivational T-marker correspondence of early Katz and Fodor [[FN14]], but rather focussed on the level of surface structure and the question of what other levels of syntactic representation might have to feed into semantic interpretation (Jackendoff 1972).

The earliest introduction of Montague's work to linguists came via Partee (1973a, 1973b, 1975a) and Thomason (1974) [[FN15]], where it was argued that Montague's work might allow the syntactic structures generated to be relatively conservative ("syntactically motivated") and with relatively minimal departure from direct generation of surface structure, while offering a principled way to address the semantic concerns such as scope ambiguity that motivated some of the best work in generative semantics.

While "Montague grammar" was undoubtedly the principal vehicle by which the influence of model-theoretic semantics came into linguistics, there were other more or less connected lines of similar research which contributed to the ensuing cooperative linguistics-philosophy enterprise. The work of David Lewis is important in this regard, both because Lewis, who knew the work of Chomsky and other linguists quite well, was an important influence on Montague's own work via conversations and his participation in Montague's seminars, and because Lewis (1968, 1969, 1970) presented many of the same kinds of ideas in a form much more accessible to linguists. Cresswell (1973) was another related work, a book-length treatment of a similar semantic program, with a great deal of valuable discussion of both foundational issues and many specific grammatical constructions. Also Parsons (ms. 1972), Keenan (1971a, 1972b), and Thomason and Stalnaker (1973) were early and active contributors to linguistics-logic-philosophy exchanges.

By the middle of the 1970's, Montague grammar and related work in formal semantics was flourishing as a cooperative linguistics-and-philosophy enterprise in parts of the U.S., the Netherlands, Germany, Scandinavia, and New Zealand, and among individual scholars elsewhere. (By the late 1970's it was no longer possible to keep track.) The first published collection, Partee (ed., 1976), contained contributions by Lewis, Partee, Thomason, Bennett, Rodman, Delacruz, Dowty, Hamblin, Cresswell, Siegel, and Cooper and Parsons; the first issue of Linguistics and Philosophy contained Karttunen (1977) as its first article; the biennial Amsterdam Colloquia, still a major forum for new results in formal semantics, started up in the mid-70's and opened its doors to scholars from outside Europe by the late 1970's. Other conferences and workshops on or including Montague grammar were held in various places in the U.S. and Europe from the mid-1970's onward.

3.2. An example: NP interpretation.

A good example of the interesting novelty to linguists of Montague's analysis was his treatment of NPs in PTQ. One exciting idea was the uniform interpretation of all NPs as generalized quantifiers (which may have been suggested to him by David Lewis; see Note 12), which allowed one to be explicit about their important semantic differences, as in generative semantics treatments, while having a single semantic constituent corresponding to the syntactic NP constituent, and unlike the distribution of pieces of NP-meanings all over the tree as required by the first-order-logic-like analyses linguists had been trying to work with (because linguists generally knew nothing about type theory, certainly nothing about generalized quantifiers.) Dependence on first-order logic had made it impossible for linguists to imagine giving an explicit semantic interpretation for "the" or "a" or "every" or "no" that didn't require a great deal of structural decomposition into formulas with quantifiers and connectives, more or less the translations one finds in logic textbooks. The generative semanticists embraced such structures and made underlying structure look more like first-order logic, while the Chomskyites rejected such aspects of meaning as not belonging to any linguistic level and gave no explicit account of them at all. One can speculate that the rift might never have grown so large if linguists had known about generalized quantifiers earlier; the productive teamwork of Barwise and Cooper (1981) is a beautiful example of how formal properties and linguistic constraints and explanations can be fruitfully explored in tandem with the combined insights and methodologies of model theory and linguistics, and generalized quantifiers have continued to be a fertile domain for further linguistically insightful work exploiting formal tools (see the papers on Generalized Quantifier Theory by Keenan and Cooper in Section III.)

A second important aspect of NP interpretation in PTQ is the handling of scope via differences in analysis trees. The treatment (and sometimes even the existence) of the scope ambiguity of (1) was a matter of considerable controversy in the interpretive/generative semantics debates. PTQ used a "Quantifying In" rule which resulted in a single syntactic tree structure for (1) but two different analysis trees [[FN16]], an important illustration of the "rule-by-rule" approach.

(1) A unicorn eats every fish

McCawley (1981) points out the similarity between Montague's Quantifying In rules and the generative semantics Quantifier-Lowering rule, and there are indeed important similarities between what one might look at as a command relation in a Montagovian analysis tree and a command relation in a generative semantics underlying structure or a GB LF. The differences in conception are nevertheless interesting and important, with Montague's approach more like the old "item-and-process" (vs. "item-and-arrangement") grammars or like Zellig Harris's underappreciated algebraic work (e.g., Harris 1968) which also treats structural similarity between languages in terms of "history of rules applied in derivations" rather than in geometrical configurations at selected levels of representation. Montague's Quantifying-In rule was in fact outside the bounds of what linguists would have called a single rule, since it simultaneously substituted a full NP for one occurrence of a given "variable" (he_n) and pronouns of appropriate gender, case, and number for all other occurrences of that same variable.

The proper treatment of scope ambiguity and the binding of pronouns is of course a continuing area of controversy with profound implications for the

nature of the syntactic and semantic components of grammar and their interface. Cooper (1975) invented "Cooper storage", with its concomitant weakening of compositionality, as a means to avoid even a derivational ambiguity in a sentence for which there is no independent syntactic motivation for positing ambiguity. Scope ambiguity is also the only known phenomenon for which GPSG (Gazdar et al, 1985) had to choose between abandoning context-freeness or abandoning compositionality; they opted for the latter in quietly presupposing Cooper storage for quantifier scope. May (1977) introduced Quantifier Raising, approximately the mirror image of the generative semantics rule of Quantifier Lowering, and then made the startling proposal that c-command at LF does not in fact disambiguate quantifier scope, thereby abandoning the otherwise respected principle that the input to semantic interpretation must be a disambiguated syntax, and that whatever "logical form" may mean, being truth-conditionally disambiguated is part of it. Other proposals for dealing with quantifier scope can be found in contemporary literature, including the "Flexible Categorial Grammar" approach of Hendriks (1987, 1993) and others. This has been and undoubtedly will continue to be an important arena for exploring consequences of various conceptions of rules and representations and the connections among them, as are the equally varied and controversial proposals concerning the syntax and semantics of pronouns and other "bindable" expressions. [[FN17]]. The integration of psycholinguistics and formal semantics requires some resolution of the problem of combinatorial explosion that comes with the disambiguation of such pervasive ambiguities as scope ambiguities; see Johnson-Laird (1983), Fodor (1982). It is hard to imagine all the ways in which recent linguistic history might be different if quantifier scope did not have to be worried about at all, but as long as systematic truth-conditional differences are regarded as semantic differences, quantifier scope possibilities must be accounted for. (See the papers in Section IV of this book on Anaphora, Scope, Binding and Ellipsis for some of the contemporary ramifications of these issues.)

3.3. Function-argument structure and the reinvigoration of categorial grammar; and lambdas.

Another important legacy of Montague's work, one which has become so thoroughly absorbed into linguistics that its novelty in the early 1970's is easily forgotten, is the idea of seeing function-argument structure as the basic semantic glue by which meanings are combined. What did we think before that? In early work such as Katz and Fodor (1963) or Katz and Postal (1964) one sees attempts to represent meanings by means of bundles of features and meaning combination as the manipulations of such feature-bundles; there were obvious problems with any semantic combinations that didn't amount to predicate-conjunction. Later logically-oriented linguists working on semantics invoked representations that looked more or less like first-order logic augmented by various "operators" (this was equally true for generative and interpretive semantics), and more generally the practice of linguists dealt in "semantic representations" without explicit attention to the interpretation of those representations. This was the practice David Lewis was deploring on the first page of his 1970 paper "General Semantics":

> "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.

> Translation into Markerese is at best a substitute for real semantics, relying either on our tacit competence (at some future date) as speakers of Markerese or on our ability to do real semantics at least for the one language Markerese." [p.18]

I believe linguists did presuppose tacit competence in Markerese, and moreover took it to represent a hypothesis about a universal and innate representation, what Jerry Fodor later dubbed the Language of Thought (e.g., Fodor 1975), and therefore not in need of further interpretation. The problems that resulted and still result, however, from making up names for operators like "CAUSE" or features like "AGENT" without addressing the formidable problems of defining what they might mean, are evident whenever one looks at disputes that involve the "same" operators as conceived by different linguists or in the analysis of different languages or even different constructions in the same language.

But let us come back to "real semantics" and the impact of seeing semantic interpretation as involving a great deal of function-argument structure (something also emphasized early by Lewis, Cresswell, and Parsons, and traceable to the work of Frege, Tarski, and Carnap.) The idea of an "intensional transitive verb" like Montague's treatment of seek had apparently not occurred to linguists or philosophers before: opacity was seen as embedding under some sentential operator, and to make the opacity of a verb like seek explicit required engaging in lexical decomposition (as suggested, for instance, in Quine 1960) to make the opacity-producing operator overt. Similarly, linguists had never thought to analyze adjectives as functions applying to nouns. "Normal" adjectives were all assumed to originate as predicates and get to prenominal position via relative-clause reduction (Bach 1968 went so far as get nouns into their head positions via relative-clause reduction as well, thereby providing a clausal structure that could contain temporal operators in order to account for temporal ambiguity in superficially tenseless expressions like "the president"), and linguists who noticed the non-predicate-like behavior of adjectives like former and alleged also noted the existence of cognate adverbs which were taken to be their sources through syntactically complex derivational relations (or equally complex derivations in an interpretivist treatment, where the "more logical" representation was derived, not underlying.)

Function-argument structure and a rich type theory go naturally together in the treatment of natural language, given the fairly rich array of kinds of constituents that natural languages contain. Even if Chierchia (1984) is correct in hypothesizing that the productive categories, those which have corresponding wh-words and/or pro-forms and not limited to a small finite set of exemplars (criteria which may not always exactly agree, but a good start), are never higher than second-order in their types, that is still a much richer type structure than was found in the classical predicate logic, which has so little diversity of types (sentence, entity, and n-place first-order predicates) as to leave linguists who employed it unaware of types at all, and to make it understandable why explicit semantics before Montague grammar seemed to require so much lexical decomposition. (See Dowty (1979) for illuminating discussion by a generative semanticist who became a leading Montague grammarian.)

The appreciation of the importance of function-argument structure also helped linguists understand much more of the original motivation of categorial grammar, a formalism which was invented and developed by Polish logicians (Lesniewski 1929, Ajdukiewicz 1935) but which was dismissed by linguists as soon as it was proven to be equivalent in generative power to context-free

phrase-structure grammar. Linguists had seen it only as an alternative syntactic formalism, either not knowing or not caring that one of its central features is the way its category names encode an intimate correspondence between syntactic category and semantic type. Categorial grammars are therefore very attractive from the point of view of compositionality; this was pointed out by Lyons (1968) and Lewis (1970); Montague (1973) used a modified categorial grammar, and Cresswell (1973) used what he christened a lambda-categorial grammar. The problem of the (supposed) non-context-freeness of English and the context-freeness of standard categorial grammar was addressed in three different ways by those four authors. Lyons and Lewis added a (meaning-preserving) transformational component to a categorial base. Montague used categorial grammar nomenclature to establish the homomorphic category-to-type correspondence among generated expressions but allowed syntactic operations much more powerful than concatenation for putting expressions together (as with the Quantifying In rule mentioned above). Cresswell added free permutations to his categorial grammar, thereby generating a superset of English, with disclaimers about syntactic adequacy and suggestions about possible filters that might be added.

As linguists (and other philosophers and logicians; see especially the work of van Benthem and his colleagues and students) have taken up the challenge of adapting categorial grammars to the demands of natural languages, a great deal of interesting work has resulted, and there would undoubtedly be even more if it were not impeded by the current tendency of GB-centrism to crowd out development of other syntactic frameworks. Luckily, there has been a substantial amount of very high-quality work in this area and it can be expected that leading ideas will continue to make their way into the dominant framework, at the least. (See Oehrle, Bach and Wheeler, eds., 1987 for a collection of "classic" and more recent papers, and Steedman's paper in this volume for a current view.) Other frameworks have been suggested which combine some properties of categorial grammar with properties of X-bar syntax or other kinds of grammars; see Flynn (1981), Ross (1981), and HPSG (Pollard and Sag 1987), which basically combines GPSG with aspects of Bach's (1984) Extended Categorial Grammar.

In section 4.2. below I mention more recent alternatives to the function-argument type structure of classical MG.

The other main topic that belongs in this section is the lambda-calculus. I have been quoted (accurately) in print as having remarked in a 1980 talk on "The First Decade of Montague Grammar" that "Lambdas changed my life." That is certainly true, and one can find many introductions to them and to their use in semantics (Partee 1973b, 1975a, Cresswell 1973, Dowty et al 1981, Gamut 1991, Partee, ter Meulen and Wall 1990, and other introductions to formal semantics). Since it is particularly difficult for me to start discussing the importance of lambdas without exceeding the time or length limits I am supposed to observe, I will only reiterate the central point that lambdas provide a particularly perspicuous tool for representing and working with function-argument structures explicitly and compositionally.

3.4. Compositionality and consequences for syntax.

I would suppose that the most important contribution of Montague's work to linguistics is attention to the importance of compositionality in the conception of the relation between semantics and syntax. This was something which some if not all linguists already accepted in some form as an important ideal, since something like compositionality has seemed necessary as part of an account of semantic competence. Probably the most explicitly compositional

prior linguistic theories were those of Katz and Fodor (1963) and Katz and Postal (1964), which as noted earlier were really theories of translation into "Markerese" rather than "real semantics". But Montague's work gave a particularly clear and rigorous account of how such a principle might be made precise, and how a strong version of compositionality could be used in both directions to affect arguments about competing syntactic analyses as well as about semantic analyses.

With the rich tools that Montague's typed intensional logic (including lambdas!) provided, it was suddenly possible to provide semantic analyses that captured the kinds of generalizations the generative semanticists had called attention to and still work with a syntax that stayed remarkably close to surface structure, even less abstract in many respects than the relatively conservative grammars preferred among interpretive semanticists (e.g infinitival complements were generated as VP complements rather than as sentential complements with subsequent Equi-NP deletion; phrasal conjunctions with "sentence-conjunction meanings" were generated directly rather than via Conjunction Reduction).[[FN18]] The real excitement of this was that natural language syntax suddenly looked much less crazy; instead of the great mystery of how English syntactic structure related to its putative logical form (which, as noted above, was generally assumed to resemble first order logic plus some trimmings, an assumption we now can see as the myopia of only being acquainted with one logic, and one which was not invented for linguists' purposes), there suddenly arose the remarkable possibility that surface structure or something close to it -- a reasonbly motivated syntactic structure of the actual natural language, at least -- might be very well designed as a logical form for expressing what natural languages express. This is the chief import of Montague's use of the expression, "English as a Formal Language", and the chief importance of his work for linguistics.

An immediate payoff of having an explicit compositional semantics for a natural language is that less burden needs to fall on the syntactic component; sameness of meaning does not require sameness of deep structure (cf. Thomason 1976), (or sameness at any other syntactic level, including "LF"). It was quickly noted that many of the arguments for syntactic relatedness that motivated various transformations were at least in part implicitly semantic; this realization then led to the new possibility of English as a context-free language (Gazdar 1982 and subsequent work in GPSG), and is probably the principal reason for the positive (although partial) correlation between preference for a non-transformational syntax (GPSG, HPSG, versions of categorial grammar, etc.) with work in formal semantics.

Compositionality and model-theoretic semantics together brought the responsibility for providing an explicit interpretation for whatever "operators" or functors one included in a semantic analysis, and this led to a flowering of research on topics such as tense and aspect, the semantics of determiners, modal verbs, conditionals, questions, plurals and mass nouns, and other such topics that had not been on center stage when semantics was approached principally in terms of configurational representations which were good for elucidating scope ambiguities and the like but silent on many other semantic issues. The substantive articles in sections VI and VII of this volume concern the fruits of two decades or more of work on topics which were largely absent from the linguistics agenda before the advent of formal semantics.

3.5. Controversies and critiques.

There have been many different sources of controversy within linguistics

and philosophy concerning various aspects of the Montague grammar program, in addition to the expected continuing debates over the proper analysis of particular phenomena. Many linguists were unimpressed by Montague's syntax: while the rule-by-rule "bottom up" derivational approach offered an interesting and important perspective and constraint on possible ways to look at the syntax-semantics relation, the actual syntactic operations were unconstrained. Linguists would not consider Montague grammar a linguistic theory without an accompanying theory of constraints on the syntactic operations; diversity of opinions on the best way to go about this (among those who found the other aspects of Montague's program worth exploration) led to a distinction between "Montague semantics" (note the title of Dowty et al 1981), which became the core of the foundation of formal semantics more generally, and "Montague grammar", which has survived more as a collection of ideals and ideas and technical tools than as a specific linguistic theory of grammar per se; see section 4.4 below.

Another perennial source of controversy has been the possible-worlds basis of the analysis of intensionality in Montague's semantics. Most although not all linguists and philosophers consider it an inadequacy that all logically equivalent sentences are treated as having the same semantic interpretation when propositions are analyzed as sets of possible worlds. This perceived inadequacy together with the insistence of philosophers like Montague and Lewis on distinguishing the description of a language from the description of the language-user's knowledge of the language (a principled stand which is markedly at odds with the Chomskian program of equating grammar with what is in the head) has led some linguists and philosophers to dismiss the Montagovian program as foundationally unsuitable for a linguistic theory. This dismissal is not limited to linguists who prefer representational approaches, but also comes from the influential segment of the cognitive science community that models language processing and cognition in general in terms of formal processes on symbolic representations. The formal semantic response has been severalfold: (i) a critique of proferred representational theories of intensionality as even more inadequate [[FN19]]; (ii) attempts to develop more adequate logics and model structures (see sections 4.2, 4.3); and (iii) linguistic, philosophical, and psycholinguistic explorations of issues of "psychological reality" and the possibility or impossibility of reconciling the Chomskyan and the Montagovian views about the nature of grammar (Partee 1979a,b, 1982, 1989a, Johnson-Laird 1983, Stalnaker 1984, Soames 19??, Dowty et al 1981, Chapter 6, sec.IV), some of which has suggested interesting differences between semantics and other aspects of grammar. (Note for instance the emergence of the idea that LF is basically another level of syntax, with "real semantics" something that goes beyond linguistics proper (Chomsky 19??).)

Another controversial issue, of course, is the principle of compositionality itself, as already noted in section 2.3. Formal semanticists themselves have not been uniform in their attitudes toward the absoluteness of the compositionality principle, but internal disputes have been mild in comparison to such basic attacks as that in Chomsky (1975), where it is suggested that compositionality is in conflict with the principle of autonomy of syntax. Partee (1975b) argues that on the one hand, "descriptive" autonomy is part of Montague's program: the syntactic algebra is a separate subsystem, so syntactic rules do not appeal to or involve any semantic properties of expressions; and on the other hand, "explanatory" autonomy is methodologically a working hypothesis about which reasonable people can disagree. One can easily understand Chomsky's negativity towards Montague's remark that he failed to see any interest in syntax other than as a preliminary to semantics;

on the other hand, it seems to me quite worthwhile that some linguists should pursue the task of seeing how much of syntax they can explain without any assumptions about semantics and others see how much of syntax and semantics they can explain assuming a strong version of the compositionality principle. In addition to such critiques "from outside", there have been and still are controversies among formal semanticists concerning whether one or another theory is properly compositional, or how strong a version of compositionality is reasonably imputed to the structure of natural languages: see Janssen 1983, Partee 1984, Chierchia and Rooth 1984, and the recent debates between Groenendijk & Stokhof and Kamp concerning whether Kamp's DRT is or can be made to be compositional, and whether that is even a crucial desideratum. (See Gamut 1991, pp. 285--96; Groenendijk and Stokhof 1991; Kamp and Reyle 1993; van Eijck and Kamp, to appear.) As these debates make clear, determining the relevant formal properties of diversely presented semantic frameworks is often difficult, and respect for the letter of compositionality is not always at the top of everyone's priority list, with many semanticists content if their semantics is sufficiently explicit and systematically related in some way to their syntax. [[FN20]] Among formal semanticists, one can approximately categorize attitudes towards compositionality into three sorts: (i) empirical: compositionality represents a major claim about the architecture of grammar, and the formal semantics enterprise is in part an investigation of whether this claim can be maintained (e.g. Partee 1975a); (ii) methodological: compositionality is adopted as a fundamental constraint on theories of grammar, so that, for instance, only grammars that include a disambiguated syntax count as well-formed grammars; the formal semantics enterprise is in part an exploration of the fruitfulness of this methodological principle (Janssen 1986; Gamut 1991, section 6.5); (iii) "mental hygiene": the principle of compositionality is not itself given any special status but only taken as one clear example of the more fundamental methdological principle that there must be a systematic relation of some sort between syntax and semantics (Kamp and Reyle 1993, Chapter 0).

Other lines of controversy and critique relate to such matters as various properties of Montague's intensional logic and his type theory, the possible bias implicit in Montague's work (and others) toward English and other Indo-European languages (but see Stein 1981, Gil 1982, 1988, Bach 1993, Bach et al (eds) to appear), and the method of fragments in the face of the Chomskyan shift toward principles and parameters instead of explicit rules. Not all linguists are convinced that truth-conditions should have the central place (or any place at all) in linguistic semantics that formal semantics gives them. And some, like Lakoff (see Lakoff and Johnson 1980), criticize formal semantics for its practitioners' nearly total absence of work on metaphor (but see Indurkhya 1992), arguably an extremely pervasive feature of natural language and one of central importance for cognitive science; Lakoff's contention that formal semantics is intrinsically unsuited to the investigation of metaphor is a challenge that has not yet been sufficiently addressed.

4. The expansion, naturalization, and diversification of formal semantics.

4.1. Natural language metaphysics.

Bach (1986a) suggested the term "natural language metaphysics" to characterize a linguistic concern which may or may not be distinct from metaphysics as a field of philosophy: that is a controversy among philosophers themselves. Metaphysics is concerned with what there is and the structure of what there is; natural language metaphysics, Bach proposes, is concerned not

with those questions in their pure form, but with the question of what metaphysical assumptions, if any, are presupposed by the semantics of natural languages (individually and universally.) In the domain of time, one can ask whether a tense and aspect system requires any assumptions about whether time is discrete or continuous, whether instants, intervals, or events are basic, whether the same "time line" must exist in every possible world, etc.

Two prominent examples of such research which have had considerable repercussions on contemporary developments in semantics can be found in the semantics of mass and plural nouns and the area of tense, aspect, and the semantics of event sentences.

Link (1983) proposed a treatment of the semantics of mass and plural nouns whose principal innovations rest on enriching the structure of the model by treating the domain of entities as a set endowed with a particular algebraic structure. In the model Link proposes, the domain of entities is not simply an unstructured set but contains some subdomains which have the algebraic structure of semilattices. A distinction is made between *atomic* and *non-atomic* semilattices. Intuitively, atomic lattices have smallest discrete elements (their atoms), while non-atomic ones (really "not necessarily atomic") may not.

These atomic and non-atomic join semilattice structures, when used to provide structures for the domains of count and mass nouns respectively, give an excellent basis for showing both what properties mass and plurals share and how mass and count nouns differ, as well as for formally elucidating the parallelism between the mass/count distinction and the process/event distinction (Bach 1986b.) Some brief introductions to the main ideas can be found in Bach (1986b), Partee (1992, 1993) and in Landman's contribution to this volume; for more complete expositions, see Link (1983), Landman (1989, 1991).

A chief payoff is that these lattice structures also make it possible to give a unified interpretation for those determiners (and other expressions) that are insensitive to atomicity, i.e. which can be used with what is intuitively a common interpretation for mass and count domains, such as *the*, *all*, *some*, and *no*. *The*, for instance, can be elegantly and simply defined as a "supremum" operation that can be applied uniformly to atomic and non-atomic structures. "Count-only" determiners such as *three* and *every* have interpretations that inherently require an atomic semilattice structure.

One of the most important features of this analysis is that the mass lattice structure emerges as unequivocally more general than the count noun structure, i.e. as the unmarked case. The domains of mass noun interpretations are simply join semilattices, unspecified as to atomicity. Atomic join semilattices are characterized as the same structures but with an added requirement, hence clearly a marked case. This means that languages without the mass/count distinction are describable as if all their nouns are *mass* nouns; we need not seek some alternative structure that is neutral between mass and count, since mass itself turns out to be the neutral case (see also Stein 1981.)

Another area which has been fertile ground for hypotheses about natural language metaphysics has been tense and aspect, together with the study of event sentences, generic sentences, and modality. Researchers have argued from a variety of points of view for the addition of events as basic entities (Davidson 1967, Parsons 1986,1990, Bach 1986b, Kamp 1979, Higginbotham 1983, and others), and several have argued for an analogy between the structure of mass vs. count nouns and processes vs. events (Bach 1986b).

In early situation semantics as developed in Barwise 1981 and in Barwise and Perry 1983, the ontological status of situations and "situation types" was

a matter of some controversy, especially with respect to those authors' avoidance of possible worlds or possible situations. Subsequent work by Kratzer and by some of her students has developed the possibility of letting situations, construed as parts of worlds, function both as individuals (analogous to events, playing a direct role in the interpretation of event nominals, for instance) and as "world-like" in that propositions are reinterpreted as sets of possible situations and expressions are evaluated at situations rather than at world-time pairs. (See e.g. Kratzer 1989a,b, Berman 1987, Portner 1991, Zucchi 1989.) The rich research opened up by this development may shed light not only on the linguistic constructions under study but on properties of cognitive structurings of ontological domains which play a central role in human thought and language.

4.2. Developing more adequate logics, semantic algegras, model structures.

Of course much of the work in formal semantics over the last 25 years has been directed at the analysis of particular constructions and semantic phenomena in natural language; this work is well represented in other chapters in this handbook and is too extensive to begin to review here. In this section we very briefly review a small sample of work which has involved alternatives to or modifications of aspects of the formal framework -- the choice of logic, type theory, model structures, etc. These developments have often involved the collaboration of linguists with logicians, philosophers, and mathematicians.

Just as Montague's work freed linguists from many of the constraints imposed by a rigid adherence to classical first-order predicate logic, so later developments have freed linguists from some of the constraints of Montague's particular choices in his intensional logic and the type theory of PTQ and opened up new perspectives on quantification, anaphora, context-dependence, intensionality, and many other fundamental semantic phenomena. Relatively few of these developments involve genuinely "new" logics or formal devices; most rather involve new ideas about the application of existing logical or algebraic tools to linguistic phenomena.

The work of Kamp and Heim beginning in the early 1980's is one of the important recent developments. Kamp 1981 and Heim 1982 offer solutions to certain problems involving indefinite noun phrases and anaphora in multi-sentence discourses and in the famous "donkey-sentences" of Geach (1962) like (2) and (3).

(2) Every farmer who owns a donkey beats it.
(3) If a farmer owns a donkey, he beats it.

On their theories, indefinite and definite noun phrases are interpreted as variables (in the relevant argument position) plus open sentences, rather than as quantifier phrases. The puzzle about why an indefinite NP seems to be interpreted as existential in simple sentences but universal in the antecedents of conditionals stops being localized on the noun phrase itself; its apparently varying interpretations are explained in terms of the larger properties of the structures in which it occurs, which contribute explicit or implicit unselective binders whcih bind everything they find free within their scope.

From a broader perspective the Kamp-Heim theories have brought with them important fundamental innovations, most centrally in the intimate integration of context-dependence and context change in the recursive semantics of natural language. A related important innovation is Heim's successful formal integration of Stalnaker's (1978) context-change analysis of assertion with

Karttunen's (1976) discourse-referent analysis of indefinite NPs.

Kamp's and Heim's work has led to a great deal of further research, applying it to other phenomena, extending and refining it in various directions, and challenging it. Heim herself has been one of the challengers, arguing for a revival of a modified version of Evans' (1980) "E-type pronouns" in Heim (1990). One interesting alternative that has been developed in part in connection with a claim that Kamp's Discourse Representation Theory is insufficiently compositional is "Dynamic Montague Grammar", developed by Groenendijk and Stokhof 1990,1991 and extended by colleagues in Amsterdam and elsewhere (see Chierchia 1992).

One line of my own recent research also concerns the interaction of quantification and context-dependence, in a slightly different way, starting from the observation of Mitchell (1986) that open-class context-dependent predicates such as local and enemy behave like bound variables in that they can anchor not only to utterance contexts and constructed discourse contexts but also to "quantified contexts" as discussed in Partee (1989).

An area in which there has been considerable diversification is in the type theory, which is central to what sorts of semantic categories a framework will have and what the basic semantic combining operations are like. Modifications can be relatively small as with Gallin's (1975) two-sorted type theory Ty2, which gives to possible worlds their own primitive type and constructs all complex types uniformly as functor types; this difference is formally rather small but can make a considerable difference to the form of linguistic analyses: see Gamut (1991, v.2., section 5.8) for an introductory discussion. Other alternative type theories differ in such dimensions as choice of primitive types, choice of formation rules for complex types (Cartesian product types, recursive types, etc.), possibilities of polymorphic types and type-shifting mechanisms, etc. (see Turner (to appear)).

Montague required all functions to be total. There have been arguments from many different directions for allowing partial functions. Arguments for partiality are sometimes (not always, and not intrinsically) accompanied by arguments for relations rather than functions as the principal non-primitive types; these two changes correspond to two different ways one can loosen up the notion of functions. Partiality introduces some complexity in the formal apparatus (to cope with the consequences of undefinedness) but offers advantages in non-artificiality and in epistemological dimensions (see Landman 1991). Major advances in the incorporation of partiality into a Montague-style formal semantics were made in recent work of Muskens (Muskens 1989a, 1989b, 1989c.)

It was mentioned in section 3.5. that one criticism of Montague's semantics was that intensions analyzed as functions from possible worlds to extensions are not intensional enough: logically equivalent expressions of any category are then counted as semantically identical. Of the many responses to this problem, one that has a wide range of potential consequences is to replace the background metatheory, substituting a property theory for the normally presupposed set theory. (The principal feature which distinguishes all property theories from all set theories is the rejection of the axiom of extensionality.) The notion of "function" normally assumed in formal semantics, including when we speak of functions from possible worlds to something else, is the very extensional notion of function found in the Russell-Whitehead set-theoretic construction of mathematics, which identifies a function with the set of its argument-value pairs. The pretheoretic notion of function seems not to be so extensional, but rather somewhere in between the very procedural notion of algorithm and the very extensional standard notion: we can make intuitive sense both of two different algorithms producing

the same function and of two different functions turning out to have the same input-output pairs. Property theory represents an attempt to provide an intrinsically intensional foundation for those domains for which the extensionality of set theory appears to have undesirble consequences. Different proposals for property theory have been advanced in recent years; none has yet succeeded in widely supplanting set theory, but their existence offers linguists new options for the analysis of intensionality. (See Chierchia and Turner (1987), Turner (1987, 1989) and Chierchia et al, eds. (1989).)

The work mentioned above is of course just a small sample of important current research; in many cases it is the analysis of subtle semantic phenomena such as anaphora and nominalization that has provided and continues to provide the impetus for important advances in theoretical frameworks.

4.3. Developments in theories of grammar and lexicon.

This section is very brief; there are other chapters in this Handbook devoted to the role of semantics in various theories of grammar, and here we confine ourselves to a few remarks relating the evolution of formal semantics with other developments in theories of grammar and of the lexicon.

In section 3.4. we noted a number of effects of Montague Grammar on syntax. Both the availability of a powerful new semantic component and dissatisfaction with Montague's own unconstrained syntax contributed to efforts by a number of linguists to devise more constrained syntactic components that would be compatible with Montague's semantics while meeting linguistic criteria of syntactic adequacy. Cooper and Parsons (1976) showed how a Montague semantics could be incorporated into either a generative semantics or interpretive semantics sort of framework for a fragment that matched that of PTQ. The early attempts of Partee (1976, 1979a), Bach (1976, 1979) and others to blend Montague grammar with a constrained transformational grammar were soon supplanted by the introduction of theories which eliminated transformations altogether, as in the work of Gazdar (1982) and unpublished work by Bach and Saenz, leading to the rapid development of a variety of sorts of "monostratal" syntax as mentioned in section 3.4. While the question of whether natural languages are context-free has remained controversial, research on "slightly context-sensitive" grammars has continued to progress, and both the formal semantics community and to an even greater degree the computational linguistics community have been hospitable and fertile environments for the exploration of varieties of non-transformational grammars, including unification grammars, various kinds of categorial grammars, GPSG, HPSG, and TAG grammars (see Joshi et al 1975, Joshi 1985 for classic works on TAGs, Shieber 1986, Kay 1992 for unification grammars.) Other linguists have developed the option of taking the GB level of LF as the input to compositional semantic rules, departing further from classical MG's approach to syntax but making use of many of the valuable ideas from Montague's semantics, and still paying attention to compositionality in the relation between LF and the model-theoretic interpretation (See von Stechow 1991 and Heim and Kratzer (unpublished).) Bresnan's LFG was first given a model-theoretic semantic component by Halvorsen (1983), and LFG also figures in some of the computational approaches in Europe that incorporate aspects of formal semantics.

Other theoretical approaches should be mentioned because they represent in certain respects relevant alternatives to rather than "descendents" of Montague Grammar (although the family trees in these areas are never neat): One is game-theoretical semantics (see e.g. Hintikka and Kulas 1985), with its

"inside-out" alternative version of compositionality and its emphasis on interpretation as a verification-falsification game between the language-user and "Nature", truth consisting in the existence of a winning strategy on the part of the language-user. Another is Situation Semantics (Barwise and Perry 1983, Cooper 1986, 1987, Halvorsen 1988, Cooper et al, eds., 1990), which is intended as an alternative to Montague's semantics and may itself be combined with various sorts of syntax, and which has emphasized the situatedness of language in context, partiality, extensionality, and indexicality, and has advocated replacing possible worlds with (actual) situations and situation types in various ways. (A very different development of the integration of (possible) situations into formal semantics, much more as a refinement of Montague's semantics than an alternative to it, can be found in the work of Kratzer (1989a, 1989b) and her colleagues and students (Diesing 1990, 1992, Portner 1992, Partee 1991).) A third approach which is on the borderline between "descendent" and "alternative" is Kamp's Discourse Representation Theory (Kamp 1981, Kamp and Reyle 1993), discussed in his article in this volume; note that the work of Heim (1982), which presents a very similar theory of indefinites, anaphora, context-sensitivity, context change, is formalized in a manner that is completely consistent with Montague's Universal Grammar, so the choice of departing from strict compositionality and claiming an indispensable role for the intermediate DRS "box-language" is a choice independent of those leading ideas of Kamp and Heim.

There are of course many more approaches to syntax (and semantics) than have been mentioned here; some are theoretically too clearly incompatible with formal semantics to have led to cooperative efforts, some perhaps only accidentally separated in time or space or attention from researchers in the formal semantics community (as was the case until recently, for instance, with the Prague School work on dependency grammar and theories of topic-focus structure as an integral part of grammar with semantic as well as pragmatic import; see Hajicova, Partee and Sgall (in preparation).) Other approaches may not have been mentioned here because this author assumed, correctly or incorrectly, that they were similar enough to mentioned approaches, or for limitations of time and space, or by oversight or ignorance.

There have also been interesting developments in lexical semantics related to the issues and formal tools that have been brought into linguistics with the development of formal semantics. Before Montague Grammar, semantics was largely lexical semantics plus syntax-like investigations of relatedness between sentences. What issues in lexical semantics tended to preoccupy linguists? Well, linguists are always looking for ways of getting at "structure". In semantics this often led to proposals for decomposition into primitive concepts or "semantic features". Antonomy was once on the list of important semantic properties to be captured by a linguistic account (e.g. Katz and Fodor 1963); it is no longer much mentioned, although the fact that "opposites" generally have the same meaning except for one salient "feature" renders them a rich area for uncovering sublexical structure (and, by the way, a stimulating domain for undergraduate research projects.) One of the radical aspects in Montague's work was the relegation of most of lexical semantics to a separate "empirical" domain; the only aspects of lexical semantics that he included in grammar were what could be characterized in terms of type structure, explicit logical definition, or meaning postulates (a term from Carnap (1952) later applied to what Montague characterized as constraints on possible models.) Meaning postulates (see Dowty 1979 for general discussion and important early applications in the domain of aspect and Aktionsart; but also see Zimmermann 1993 for some recent cautions) can be seen as ways of spelling out model-theoretic content of what linguists represent as semantic

features.

One example of the kind of lexical semantics work that arose in the context of formal semantics starts from considering adjectives as functions that apply to nouns as arguments; adjectives are then naturally subclassified as intersective, subsective, and non-subsective, with the intersective ones corresponding to the first-order logic idea of adjectives as predicates that combine with their nouns via simple predicate conjunction. (See Kamp and Partee (forthcoming) for an introduction to adjective semantics, as well as some investigation of the possibility of melding some aspects of prototype theory with formal semantics in the analysis of vague concepts.) Another very rich example is the lexical classification of determiners in terms of properties like "monotone increasing/decreasing on their first/second argument", "weak/strong" and the like; these investigations are a central part of generalized quantifier theory. Lexical semantics has been greatly enriched by the greater structure that has been imposed on the basic domains of entities and events by work such as Link's (1983) proposal for modelling atomic and non-atomic part-whole structures by appropriate semilattices, and proposals by Bach, Link, Dowty, Krifka and others of comparable structures for the domains of eventualities and situations. These structures allow much more to be said about the semantics of determiners, mass and count nouns, verbs and auxiliaries. Portner 1992 is a good illustration of the new possibilities that are available: Portner makes fine-grained semantic distinctions among kinds of nominalizations and the different verbs and constructions that embed them, in a way that wasn't possible with Montague's original model theory, but became possible with advent of Kratzer's work on situations and Link's algebraic perspective on the structure of such domains.

The lexicon is one of many areas in which there is a great need for research on a typologically wider variety of languages, including polysynthetic languages where much more of the grammar takes place at the level of the word; see Bach (1993) for a start.

There are of course many approaches to lexical semantics that are more or less independent of formal semantics (see, for example, the article by Levin and Rapoport in this Handbook), and one may expect an increasingly fruitful interchange of ideas as model-theoretic approaches pay increasing attention to lexical as well as "structural" semantics.

5. Current perspectives.

Within and around the field of formal semantics, there is a great deal of diversity, as the foregoing discussion has tried to make clear. There does exist a (loose) "formal semantics community" across which discussion and debate is possible and fruitful, with Montague Grammar serving as a reference point in the background. No one of its properties is universally accepted by people who would be willing to identify themselves as doing formal semantics or model-theoretic semantics or "post-Montague" semantics, but there is a shared sense that Montague's work represented a positive contribution to ways to think about semantics in linguistics, and an introductory course or course sequence in formal semantics normally includes either an explicit "Montague grammar" component or at least many of the formal tools and concepts that were central in Montague's work.

The relation of formal semantics to "generative grammar" is also diverse, as partially described in section 4.3 above, and will undoubtedly continue to be so. For reasons that are undoubtedly more sociological than scientific, the formal semantics community has tended to be characterized by a spirit of openness to alternative theories and a recognition of the value of exploring a

range of options deeply enough to begin to evaluate their relative merits and disadvantages in a substantive way. The present decade can be expected to be a period of continuing development of approaches that differ along many of the dimensions discussed above, with continuing interaction of linguists, logicians, philosophers, and researchers in computational linguistics and AI.

The connection between formal semantics and philosophy is weaker now than it was in the early years of MG, at least in the United States, where philosophical attention seems to have shifted away from the philosophy of language and in the direction of philosophy of mind and foundations of cognitive science. The situation in the Netherlands, however, is interestingly different: there the strong tradition of "Informatica" (roughly, information theory) has fostered a long-standing cooperation among mathematicians, logicians, philosophers, computer scientists, and (some) linguists, as evident in the co-authorship of Gamut (1991; original Dutch edition 1982) [[FN21]] and the founding in the late 1980's of the interdisciplinary ITLI (Institute for Language, Logic, and Information) at the University of Amsterdam which led to the founding in 1990 of the European Foundation for Logic, Language, and Information which sponsors a new journal of the same name and annual summer schools that always include courses on the latest developments in formal semantics. The newest journal (first volume 1992) in formal semantics edited in the U.S., on the other hand, is one that specifically aims to integrate formal semantics more closely into linguistic theory, as suggested by its name, Natural Language Semantics. (The first journal, and still a central one, for the development of formal semantics has been Linguistics and Philosophy.) These developments point to an increasing specialization into more logical, computational, and linguistic aspects of formal semantics, but with continuing overlap and interaction.

Many of the most fundamental foundational issues in formal semantics (and in semantics as a whole) remain open questions, and there may be even less work going on on them now than there was in the 1970's; perhaps this is because there is more work by linguists and less by philosophers, so the empirical linguistic questions get most of the attention now.

It would be foolhardy (as well as too lengthy) to try to summarize topical areas of current active investigation. The table of contents of this handbook represents one perspective on what topics are currently of central interest, although any such list is always an over-rigidification of constantly shifting boundaries, and one can never anticipate the next unexpected breakthrough that may open up some currently neglected domain or suggest brand new questions about old familiar subjects.

Since this article has been in large part a historical overview, it doesn't have a conclusion. It is possible in the 1990's to have some historical perspective on the 1960's and the 1970's, and to some extent on the 1980's, but the closer we come to the present, the more inconclusive any survey is bound to be. The only possible conclusion is wait -- no, work! -- and see.

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FOOTNOTES

1. See for instance the references to Lewis (1968) in Lakoff (1968), to Geach (1962) in Karttunen (1969), and the evidence of awareness of logical and philosophical concerns in Keenan (1971a,b), Karttunen (1971), McCawley (1971), Bach (1968) and the volume Davidson and Harman (1972), in part a proceedings from one of the earliest linguistics and philosophy conferences (in 1969), one to which Montague was not invited.

2. See the rebuff by Chomsky (1955) of the exhortation to collaboration made by Bar-Hillel (1954).

3. Quine was evidently not satisfied by these advances; Quine (1970) expresses as much aversion to intensions as Quine (1961) and Quine (1960), although possible worlds semanticists generally considered it one of their major accomplishments to have satisfactoriy answered the important concerns Quine had raised concerning quantifying into modal contexts.

4. The variant type system Ty2 of Gallin (1975) is a possibly more perspicuous version of Montague's typed intensional logic, especially with respect to explicitly showing the ubiquity of function-argument structure in the analysis of intensions. See Turner (to appear) for fuller discussion of type theories, something which linguists in general were encountering for the first time in Montague's work.

5. I recall learning this from one of Montague's UCLA colleagues or former students, but I no longer recall who: probably David Lewis or David Kaplan or Michael Bennett or Hans Kamp, but my misty memory makes a proper acknowledgement impossible.

6. When I once mentioned to him the linguist's preferred conception of universal grammar as the characterization of all and only possible human languages, his reaction was to express surprise that linguists should wish to disqualify themselves on principle from being the relevant scientists to call on if some extraterrestrial beings turn out to have some kind of language.

7. Three good references include Halvorsen and Ladusaw (1979), Link (1979), Janssen (1983).

8. Actually, there is a way of respecting the homomorphism requirement while working with semantically ambiguous expressions, and that is to employ the strategy of Cooper (1975) of working with "sets of meanings" as the semantic objects, mapping each (possibly ambiguous) linguistic expression onto the semantic object which consists of all of its possible meanings; not all kinds of ambiguity are amenable in a natural way to this kind of treatment, but Cooper's device of "quantifier storage" for handling scope ambiguities for which there is no independent evidence of syntactic ambiguities is one of the serious options in this domain.

9. "It appears to me that the syntactical 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." (from the notorious footnote 2 of UG, p.223 in Montague (1974). Footnote 2, which goes on to criticize other aspects of "existing syntactical efforts by Chosmky and his associates", was not designed to endear Montague to generative linguists, although in the beginning of the paper he does present himself as agreeing more with Chomsky than with many philosophers about the goals of formal theories of syntax and semantics.

10. but not indispensable; the lambda-calculus just gives one very good way to provide compositional names for functions, and function-argument structure was one of Montague's principal ways, following Frege, of providing a compositional interpretation of complex syntactic part-whole structures.

11. The use of individual concepts as central to the interpretation of nouns and noun phrases was mostly abandoned in later work, following the lead of Bennett (1975); see Dowty et al (1981) for discussion, but also see Janssen (1983) for defense.

12. Although it was principally through PTQ that this analysis became influential in linguistics, this may be one of the ideas that Montague got from David Lewis, since it also appears in Lewis (1970), embedded in a theory which combined a categorial grammar phrase-structure with a transformational component.

13. There has not been much explicit discussion of pro's and con's of the method of fragments in theoretical linguistics, and the methodological gap is in principle even wider now that some theories don't believe in rules at all. In practice the gap is not always unbridgeable, since e.g. principles for interpreting LF tree structures can be comparable to descriptions of rules of a Montague grammar whose analysis trees those LFs resemble.

14. See Bach's (1976, 1979) reexamination of generalized transformations in this context.

15. The author sat in on some of Montague's seminars at UCLA along with David Lewis, who was very helpful in interpreting Montague to her. The 1970 two-part workshop at which Montague presented PTQ in September and Partee (1973a) was presented as commentary in December took place only months before Montague's untimely death in early 1971. Partee began teaching seminars on Montague grammar in 1971 and 1972 at UCLA, Stanford, the Philosophy and Linguistics Institute organized by Donald Davidson and Gil Harman at UC Irvine (Summer 1971), and the UCLA, and the 1972 California Linguistics Institute at UC Santa Cruz; and continued at the University of Massachusetts at Amherst from 1972 in courses and seminars and at the 1974 Linguistic Institute in Amherst. In the course of giving these seminars and various talks on Montague Grammar and transformational grammar, the author was greatly aided by colleagues and students, especially David Kaplan, David Lewis, Frank Heny, Michael Bennett, Donald Victery, Enrique Delacruz and Richmond Thomason at the beginning, and Terry Parsons and Ed Gettier at UMass.

16. The generation of a single syntactic tree structure requires Partee's (1973b) amendment to the effect that the syntactic rules generate trees rather than strings.

17. Linguists not bound by the commitment to making truth conditions and entailment relations central to semantic adequacy criteria have the possibility of not representing scope as a linguistic ambiguity at all. This was a possibility sometimes entertained in Chomsky's earlier work, allowed for in current Prague school work such as Hajicova and Sgall (1987), explored in the context of parsing by Hindle and Rooth (1993), and in the context of Discourse Representation Theory by Reyle (1993); see also Poesio (1991, 1994).

18. Earlier proposals for directly generated phrasal conjunction in the transformational literature, by Lakoff and Peters, by Schane, and by others, concerned "non-Boolean" and; "Boolean" and was quite uniformly believed to be syntactically derived from sentential conjunction.

19. Max Cresswell (p.c.) once remarked that theorists who say that their theories have no problem with propositional attitudes usually turn out not to have developed their theories as far as those theories for which one can identify what the problems are.

20. But see Janssen's (1983) cautionary advice that failures of compositionality are often symptoms of defects in analysis.

21. "L.T.F. Gamut" is a pseudonym for five co-authors: the philosophers Jeroen Groenendijk and Martin Stokhof, the logicians Johan van Benthem and Dick de Jongh, and the linguist Henk Verkuyl; the initials L.T.F. stand for the Dutch words for "logic, linguistics, philosophy", and "Gamut" is derived from the authors' (then) institutions, the Universities of Groningen, Amsterdam, and Utrecht.

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