

Formal semantics for natural language

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Formal Semantics for Natural Language is the study that makes use of tools from formal or symbolic logic to analyse the meaning in the languages that human beings use for everyday communication. But what has to do logic in the study of natural language meaning? Well, the answer to this question depends first on what the term 'logic' means. If we reduce the meaning of 'logic' to the classical first-order predicate logic, then the answer is that the use of logic is hopeless in order to analyse meaning in natural language. This reductive assumption on the nature of logic, together with the belief on the inherent incoherence of natural language, was the main reason for the idea that formal semantics for natural language was totally insufficient and that became the official opinion for many logicians, philosophers, and linguists. Even Alfred Tarski, who, because of his definitions of Truth and Logical Consequence for formal languages, is considered the father of formal semantics, thought that it was impossible to build up an adequate formal semantics for natural language. It was in the 70's when Richard Montague, using all the tools that modern logic put at his hands (not only first-order logic, but also, higher-order logic, type theory, lambda calculus, intensional logic with possible world semantics, etc.), showed us that it was possible to treat natural language, specifically English, as a formal language.

From that point, the results in formal semantics for natural language have been many and rich. In this paper we will try to show which are the main contributions made by formal semantics to the comprehension of meaning in natural language. For that purpose nothing better than presenting, necessarily briefly, three of the most important theories in this field nowadays: Montague Grammar, Discourse Representation Theory and Situation Semantics. Obviously, we will not be able to offer a complete and detailed description of any of them, but we hope the present paper will be useful for drawing out a panoramic view of the current work in the field. Thus, in the first section we will sketch the proposal made by Richard Montague, the so-called PTQ Grammar. In the second section, you will find a description of the main theory concerned with *discourse* meaning: Discourse Representation Theory. Next, the third section will be focused on a theory located so-

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mewhere in the border between semantics and pragmatics, and based on a general theory of information and its flow: Situation Semantics. Finally, in the last section we will draw out some general conclusions and further suggestions.

Everybody knows about the secondary role that many linguists have assigned and still assign to semantics within the linguistic enterprise. The aim of this paper would be completely fulfilled if, as a result of reading it, some of them would change or at least relativise that view. We would be glad if it would be for some use for the people that, interested in natural language, have not had the choice to approach to work on the problem of meaning, and also for the people that, though interested in the problem of meaning, has been reluctant to the formal treatments, perhaps because of making the same reductive assumption on the nature of logic mentioned above.

The Principle of Compositionality

Before going on, let us see one semantic principle which is essential for all we will say later: the principle of compositionality of meaning. This principle is very important, particularly in Montague Grammar, because, it is not only a criterion for its semantics, but also has notorious consequences on the relationship between syntax and semantics.

The principle of the compositionality of meaning, also known as 'Frege's principle', says the following: the meaning of a complex expression is a function of the meanings of its parts. Thus, in the semantics we fix the meaning of basic expressions, and the meaning of complex ones is determined by semantic rules that tell us how basic expressions combine with each other contributing to the meaning of the whole. This fact imposes certain conditions on the syntax, the semantics, and the relationship between both in the language. In the case of formal languages it is easy to see that meaning is treated following that principle. Since formal languages are artificial, we have no problem to build them up in a way to fit that principle. We cannot, on the other hand, organise natural languages just corresponding to our goals; natural languages are given to us. Hence, we have to think carefully before claiming that natural language meaning meets the principle of compositionality. Indeed, this issue has been and still is subject of intense debate. Alfred Tarski had not a very optimistic opinion on the plausibility of applying his own work to natural language. For using logical tools in the definition of meaning in a language we need a complete specification of the syntax for that language, and that did not seem very plausible for natural language at least in the 40's, when Tarski did his most fundamental work.

Anyway, the point is that the principle of compositionality presupposes the syntax. In other words, in order to analyse compositionally the meaning of a complex expression we have to consider not only such expression but also its syntactic analysis. The latter will show us which parts is the expression formed by, by means of which rules, and in which order. We will need all this information if we want to analyse the meaning of the whole expression as a function of the meanings of its parts. Moreover, in natural languages we have expressions syntactically ambiguous; expressions, which may have been built up by more than one syntactic procedure, that may lead to different syntactic analysis. In some cases, different syntactic

analysis will produce different semantic analysis. Therefore, we need the former to be able to study the latter. Let us see some classical examples to illustrate all this:

- (1) I saw a man with a telescope

This sentence has two possible readings. In one of them I use a telescope to see a man. In the other one, it is the man I saw who has the telescope. The ambiguity is created by the expression *a man with a telescope*. The issue is the position of the Preposition Phrase (PP) in the constituent structure. If the PP is in the verb argument position, then we obtain the first reading. If, on the other hand, the PP is in the argument position of the Noun Phrase (NP) *a man*; then we have the second reading. In other words, the point is the difference between these two structures:

- (2) a. $s[I\text{ VP}[saw\text{ NP}[a\text{ man with a telescope}]]]$
 b. $s[I\text{ VP}[saw\text{ NP}[a\text{ man}]\text{ PP}[with a telescope]]]$

Thus, in order to analyse the meanings of (1) we need the syntactic analysis (2a) and (2b). We call *structure ambiguity* to ambiguity phenomena such as this. But there are syntactic ambiguities which are not cases of structure ambiguity. Consider (3) below:

- (3) Everyone in the department speaks two languages.

This sentence has two possible readings too. In one of them, there are two languages, say Basque and English, spoken by everyone in the department, and it is possible for someone to speak another language too. A different reading will tell us that everyone in the department speaks only two languages, possibly different languages for each one.

We cannot explain this case of ambiguity in terms of structural ambiguity, since (3) only has one constituent structure. The explanation proposed by Montague says that the ambiguity of (3) arises from the difference in its ways of derivation. These ways of syntactic derivation will give us the same constituent structure as their result, but they will produce different meanings. For that reason, we call *derivation ambiguity* to this kind of phenomena.

The point is then that to account for meaning ambiguities the semantics needs the syntax: not only the syntactic analysis of constituent structures but also of syntactic derivations.

But the principle of compositionality not only requires a well defined syntax. At the same time, it imposes conditions to it. The compositionality principle demands that every ambiguity not based in the lexicon must be rooted in the syntactic derivation. And also that every syntactic operation must have its semantic interpretation. These requirements mean that the syntax is not autonomous within Montague Grammar. Semantic considerations will be of great relevance for proposing the syntax. Certain syntactic ambiguities will be produced by exclusively semantic reasons, and for the choice between different syntactic analysis we will use criteria of a semantic nature instead of a syntactic one.

On the other hand, we may study semantical issues without having in mind any syntactic criteria at all. Two sentences with different syntactic derivations or struc-

tures may have the same meaning. Starting from a semantic theory allows us to consider that two different sentences have the same meaning without having to assess that they are equivalent at some syntactic level as deep structure, d-structure or whatever. The unique requirement is that the different syntactic analysis of those sentences produce the same semantic interpretation.

After all these considerations, we will try now to give a structured overview on the semantic theories mentioned above, beginning with Montague Grammar as presented in Montague 1973, which is known as 'PTQ grammar'.

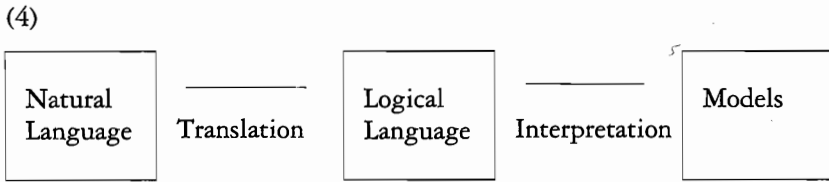
I. Montague Grammar

We call *Montague Grammar* the work made in the seventies by Richard Montague to build up a model-theoretic semantics for natural language. However, we could talk of semantics instead of grammar, since, as we shall see, his motivations and the nature of his results are semantic, and it is the semantics what determines the characterisation of the other components in the grammar. Let us see first the general organisation of Montague grammar.

I. 1. The General Organisation of PTQ

For all the reasons we have mentioned so far, the principle of compositionality has strong consequences in order to determine the general organisation of PTQ grammar. But it has more peculiarities. One of them is the link between syntax and semantics. In PTQ grammar this linkage is not direct; there is a translation to a logical language in the middle. It would be possible for a natural language to give its semantic interpretation directly, once we have its syntactic analysis. In fact, that is what Montague himself does in Montague 1970a. But in PTQ natural language expressions are first translated into expressions of a logical language, and then we get the semantic interpretation of these logical expressions.

The translation process must satisfy certain conditions. In the logical language there is no place for ambiguities. So, the semantics assigns one meaning to each logical expression. And then, if a given natural language expression is ambiguous, in the translation we have to assign to it different logical expressions. As we said earlier, if the ambiguity of a sentence is not due to the lexicon, then different syntactic analysis correspond to it, and different logical expressions to each analysis, and a different semantic interpretation to each expression. The translation process is, then, compositional too. To each lexical item corresponds one logical expression and to each logical expression one meaning. The syntactic rules tell us how complex expressions are formed starting from lexical items. To each syntactic rule corresponds one translation rule that tells us how we get the translation of the complex expression starting from the translations of the lexical items that form it. Once we have this translation we get the meaning in the same way as in the semantics of logical languages. These are, briefly presented, the main features of the general organisation of PTQ grammar, which is graphically summarised in (4):



Now we will present the necessary elements of the PTQ syntax in order to be able to understand the main features of Montague Semantics. For those who look for a more complete description and explanation, Gallin 1975, Dowty et al. 1981 and Gamut 1991, volume 2, are three excellent systematic presentations of Montague Grammar. Let us also mention Halvorsen and Ladusaw 1979 for a good description of Montague's Universal Grammar.

I. 2. The Syntax

The syntax proposed by Montague in PTQ is a categorial syntax of a special kind. Usually a categorial syntax has these four components:

- (i) a list of basic components;
- (ii) a definition of derived categories;
- (iii) the lexicon, that is, a list of all lexical items, specifying their category;
- (iv) the specification of the behavior of the only syntactic rule of concatenation.

It is this last point where Montague's syntax differs from traditional categorial syntax. Indeed, since categorial syntax is equivalent to context free rewrite rules systems, it has problems to account for some natural language phenomena. For that reason, it has been proposed to introduce a transformational component in a pure categorial syntax. Montague does not follow this option. Instead, he defines a big and heterogeneous set of syntactic rules. These rules, besides concatenation, introduce elements syncategorematically, change word order, regulate morphological form, and even sometimes do the three operations at the same time. For contemporary syntacticians these rules will have few value as explanation of syntactic operations, but we cannot forget that as Montague recognises "I fail to see any great interest in syntax except as a preliminary to semantics" (Montague 1974: 223, fn). Anyway, there are some successful proposals in order to show how we can use Montague semantics with more adequate syntactic theories (see, for instance, Par-tee 1973, 1975).

But, let us describe PTQ syntax.

First of all, we define the set of categories:

- (i) e and t are basic categories.
- (ii) If a and b are categories, then a/b and $a//b$ are categories.¹

(1) a/b and $a//b$ are different syntactic categories with the same semantic function like common nouns and intransitive verbs.

The basic categories are two: *e* (for *entity*) which does not correspond to any lexical item, and *t* (for *truth*) which corresponds to sentences; the category *a/b* is a functional category which when applied to an argument of category *b* produces an expression of category *a*. As you can see, the rule (ii) of the definition of categories is recursive, that is to say, the number of categories that produces is infinite. But Montague uses only few of them, and we will use even fewer in this introductory exposition. Here you are the list of most important categories with their abbreviation, and with the fragment of English we will study:

Categorial definition	Abbreviation	Description	Expressions
<i>e</i>	—	—	∅
<i>t</i>	—	Sentence	∅
<i>t/e</i>	IV	Intransitive Verb	<i>smoke, sleep, walk, talk</i>
<i>t//e</i>	CN	Common Noun	<i>man, woman, language, unicorn, elephant, queen, park</i>
<i>t/IV</i>	T	Term or Noun Phrase	<i>John, Mary, Bill, he₀, he₁, ...</i>
<i>IV/T</i>	TV	Transitive Verb Phrase	<i>love, speak, know, seek, find</i>

Let us see now some syntactic rules. In the table above we defined the set of basic expressions for each category *A*: let us call this set B_A . Syntactic rules have to define the set of phrases of category *A*, that is, the set that will contain, jointly with the set B_A , the set of complex expressions of category *A* formed by syntactic rules with elements of B_A . Call this set P_A . The first syntactic rule says this:

S1. For every category *A*, $B_A \subseteq P_A$.

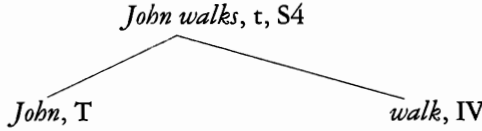
The subsequent rules will specify how complex expressions are formed. For that purpose, they have to give us three kinds of information: (i) the categories to which we may apply the rule; (ii) the category of the complex expression resulting of the application of the rule; (iii) the specification of the syntactic operation needed to get the new expression. Let us see, as an example, the fourth syntactic rule in PTQ, known as the 'subject-predicate' rule:

S4. If $\alpha \in P_T$ and $\delta \in P_{IV}$, then $F_4(\alpha, \delta) \in P_t$, where $F_4(\alpha, \delta) = \alpha\delta'$ and δ' is the result of substituting the first verb for its third person form in δ .

This rule allows us to form a sentence (of P_t) by a term (of P_T) and a verb phrase (of P_{IV}), with the subject-predicate concordance at the same time. Consider, for example, *John* $\in P_T$ and *walk* $\in P_{IV}$ (these two words are of B_T and B_{IV} , respectively, hence, by S1 are of P_T and P_{IV}). Linking them we obtain *John walks* $\in P_t$, by S4.

In Montague Grammar the derivation of an expression is represented by analysis trees. The tree for the example above is the following one:

(5)



All the nodes in the tree are labelled with an expression, its category, and the syntactic rule used to produce it except with S1.

I. 3. The translation

As we have said before, to each syntactic rule corresponds one translation rule. The translation rule corresponding to S4 is T4, namely:

T4. If $\alpha \in P_T$ and $\delta \in P_{IV}$, and if α' and δ' are, respectively, the translations of α and δ , then the translation of $F_4(\alpha, \delta)$ is $\alpha'(\wedge\delta')$.

The rules S4 and T4 constitute the most common combination of syntactic/translation rules: a rule of functional application. A syntactic rule of functional application, linking two expressions of categories A/B and B, gives an expression of category A. In our example, it links an expression of category T (= t/IV) with an expression of category IV to yield a new expression of category t. The translation rule corresponding to syntactic rules of functional application is always of the same form: we take the translation α' of the expression of category A/B and we link with the translation β' of the expression of category B, to get $\alpha'(\wedge\beta')$.²

In order to illustrate how T4 works we will use our example above. First, we need the translations of the basic expressions *John* and *walk*. The translation of the latter is quite straightforward. Intransitive verbs as well as common nouns have the same semantic function, they are one-place predicates, that is, constants that denote one set of individuals. As usual in Montague Grammar we will write the translation of *walk* as *walk'*.

The translation of terms is more complex and constitutes one of the most important features of Montague Semantics. Let us spend a little bit of time explaining it.

I. 3. 1. The translation of terms.

In principle, it is natural to consider terms like proper names and definite descriptions as referring to individuals. On the other hand, it seems that quantified terms like *every man* have to be interpreted in a different way, since it is clear that they do not denote individuals. But, one of the main features of PTQ grammar, in fact what motivates the title of the article where it was presented, is the uniform and compositional treatment of terms as quantified expressions. Let us consider this example:

(2) The symbol ' \wedge ' stands for intension. The intermediate logical language used in Montague Grammar is the Typed Intensional Logic, rich enough for accounting for intensional phenomena in natural language such as opaque context created by quotation, indirect speech, verbs expressing propositional attitudes, modality and so forth. Hereinafter through the paper we will obviate intensionality for simplicity and clarity in the exposition.

(6) Every man walks.

Using first-order logic we would translate this formula as:

(7) $\forall x(\text{man}(x) \rightarrow \text{walk}(x))$

the formula that expresses that for every individual it is true that if it is a man, it walks. Thus, *every man* would be translated as an expression asserting that all individuals that are men has the property Q:

(8) $\forall x(\text{man}(x) \rightarrow Q(x))$.

And using lambda abstraction³ on Q we would get an expression denoting all the properties such that every man (in some world w) has those properties, which is the intended interpretation in PTQ grammar:

(9) $\lambda Q \forall x(\text{man}(x) \rightarrow Q(x))$.

And now, if we substitute the property *man* for an arbitrary property P and abstract over it we get the expression:

(10) $\lambda P \lambda Q \forall x(P(x) \rightarrow Q(x))$.

(10) would be the translation for the determiner *every*, which expresses a relation between two properties of individuals (extensionally sets), a relation that is true of properties P and Q in a world if and only if all the individuals who have property P in that world have property Q in that world. If we apply this expression to the translation of *man*, that is, *man'* we get:

(11) $\lambda P \lambda Q \forall x(P(x) \rightarrow Q(x)) (\text{man}')$

an expression which refers to the set of properties Q that stand in the relation described by (10) with respect to the property of being a man. We could simplify this expression using lambda conversion and get:

(12) $\lambda Q \forall x(\text{man}'(x) \rightarrow Q(x))$.

Now, applying (12) to the translation of *walk*, namely, *walk'*, we have:

(13) $\lambda Q \forall x(\text{man}'(x) \rightarrow Q(x)) (\text{walk}')$.

And using lambda conversion:

(14) $\forall x(\text{man}'(x) \rightarrow \text{walk}'(x))$.

So, finally we get an expression almost identical to that of first-order language. But using PTQ treatment, we build up the interpretation of a term compositionally,

(3) The use of lambda operations in the study of natural language is motivated, among other reasons, by compositionality, as we can see later, and provides the language with more expressive power. Consider the first-order logic expression: (1) *man*(x)

We can get the expression to refer to the property of being a man applying lambda abstraction to (1), which produces: (2) $\lambda x[\text{man}(x)]$.

If we want to predicate this property of an individual, say, j, we would have j as an argument of the expression in (2), that is: (3) $\lambda x[\text{man}(x)](j)$.

And now we can apply lambda-conversion to (3) and get a first-order formula: (4) *man*(j).

and we can represent the semantic function of each syntactic element, something we cannot do using merely first-order logic.

Then, quantified terms are interpreted as sets of properties (or of sets), and the determiners as relations between properties. Here are the translations for the determiners *every*, *the*, *a(n)* and *one*:

$$(15) \textit{every} \Rightarrow \lambda P[\lambda Q \forall x[P(x) \rightarrow Q(x)]]$$

$$(16) \textit{the} \Rightarrow \lambda P[\lambda Q \exists y[\forall x[P(x) \leftrightarrow x=y] \wedge Q(y)]]$$

$$(17) \textit{a(n)} \Rightarrow \lambda P[\lambda Q \exists x[P(x) \wedge Q(x)]]$$

$$(18) \textit{one} \Rightarrow \lambda P \lambda Q \exists y \forall x[(P(x) \wedge Q(x)) \leftrightarrow x=y]$$

Now, the treatment of quantified terms affects the treatment of proper names. They are from the same syntactic category of quantified terms, they have the same syntactic function. Hence, they will be interpreted like quantified terms as sets of properties. Indeed, we can interpret, say, *John walks* as an assertion that the property of walking belongs to the set of John's properties, and, then, *John* would be translated as:

$$(19) \lambda P[P(j)]$$

So, now we can get the translation for the analysis tree (5) of the sentence *John walks*. The different stages in the translation process will be listed as in a proof: in each line we will put on the translation to the Montague's intensional logic (IL) as well as its justification; we will use the symbol ' \Rightarrow ' to mean 'is translated as'. Thus, we will have English expressions in the left hand of the symbol, and the translation of the expression and the justification in the right one.

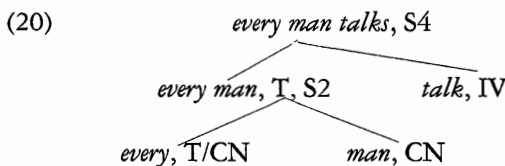
- | | | |
|----------------------|--|----------------------|
| 1. <i>John</i> | $\Rightarrow \lambda P[P(j)]$ | Basic expression |
| 2. <i>walk</i> | $\Rightarrow \textit{walk}'$ | Basic expression |
| 3. <i>John walks</i> | $\Rightarrow \lambda P[P(j)](\textit{walk}')$ | T4, 1 and 2 |
| 4. <i>walk'(j)</i> | | Lambda-conversion, 3 |

Let us see now the translation for a sentence like *Every man talks*. But before doing that, we need the analysis tree of that sentence, and for that, we need the following syntactic rule:

S2. If $\alpha \in P_{T/CN}$ and $\beta \in P_{CN}$, then $F_2(\alpha, \beta) \in P_T$ and $F_2(\alpha, \beta) = \alpha\beta$.

Then, we introduce determiners as expressions of category T/CN, that applied to expressions of category CN yield an expression of category T.⁴

With this rule at hand we can derive the following analysis tree:



(4) In fact, this is not a rule of PTQ since Montague introduces the determiners syncategorematically, but it is entirely equivalent, and more convenient for us for several reasons.

And once we have the analysis tree, and the translation rule T2 (of functional application, and then very similar to T4) corresponding to the syntactic rule S2, we can get the following translation:

1. $every \Rightarrow \lambda P[\lambda Q \forall x[P(x) \rightarrow Q(x)]]$	Basic expression
2. $man \Rightarrow man'$	Basic expression
3. $every\ man \Rightarrow \lambda P[\lambda Q \forall x[P(x) \rightarrow Q(x)]] (man')$	T2, 1 and 2
4. $\lambda Q \forall x[man'(x) \rightarrow Q(x)]$	Lambda conversion, 3
5. $talk \Rightarrow talk'$	Basic expression
6. $every\ man\ talks \Rightarrow \lambda Q \forall x[man'(x) \rightarrow Q(x)](talk')$	T4, 4 and 5
7. $\forall x[man'(x) \rightarrow talk'(x)]$	Lambda-conversion, 6

I. 4. Conclusions

We have left aside a lot of important details of PTQ grammar and Montague Grammar in general. We have only introduced a few syntactic rules and the corresponding translation rules in order to show how PTQ grammar works. But we have not seen some of the most important syntactic-translation rules that are used to account for semantic phenomena as *de dicto-de re* readings distinction, scope ambiguities, intensional contexts or anaphora.⁵ We have not seen many features of the rich Intensional Theory of Types used as an intermediate language. But, anyway, we hope that the overall idea underlying Montague's work will be clearer enough. Let us quote Montague himself:

There is in my opinion no important theoretical difference between natural languages and artificial languages of logicians; indeed, I consider it possible to comprehend the syntax and semantics of both kinds of languages within a single natural and mathematically precise theory. On this point I differ from a number of philosophers, but agree, I believe, with Chomsky and his associates. It is clear, however, that no adequate and comprehensive semantical theory has yet been constructed, and arguable that no comprehensive and semantically significant syntactical theory yet exists. (Montague 1970b).

So, as we have indicated earlier, one of the main goal of Montague is to show that formal semantics for natural language is possible and hopeful; that we can study and understand meaning in natural language as rigorously as in formal languages. Another and equally important goal is to make place for semantics as a proper part of linguistics. He met the first goal successfully; all work done in formal semantics after him shows that. The second goal is still something we have to work further.

II. Discourse Representation Theory

Discourse Representation Theory (hereinafter DRT) is the name for a semantic theory for natural language initially developed by Hans Kamp (1981) and independently by Irene Heim (1982). Two of its main characteristics are mentioned in the name. The first of them is that it concerns with the semantic interpretation of

(5) We suggest Orlowska, 1988, as a good introduction to some extensions of Montague's logic.

discourses, not with sentences as Montague semantics does. The other one has to do with the word *representation*. DRT postulates an intermediate level between linguistic expressions and reality in the relation of semantic interpretation. This level is the level of semantic representation where the information conveyed by a discourse is stored. As we have seen, in Montague grammar the intermediate level of translation to Typed Intensional Logic is not necessary, but in DRT the process from expressions to representations is not compositional, and this fact makes the level of representation an essential one in DRT.

Another important characteristic of DRT is that it is considered as a bridge over two perspectives in semantics taken as opposite: the psycho-linguistic view which relates syntactic structures to mental representations, and the logical view which relates syntactic structures to (models of) reality. In other words, DRT links the declarative or static view of meaning with the procedural or dynamic view.

But for our purposes it be better to look at the empirical motivations of DRT, that is, at phenomena like pronouns interpretation, and anaphoric relations between pronouns and indefinite terms. Phenomena which Montague grammar has problems to deal with. In that way we will have the possibility for contrasting both theories in some points.

II. 1. Anaphora

Anaphoric pronouns are those pronouns that have not a reference by itself, but take it from another noun phrase. Consider the following example:

- (1) John loves Mary and he kisses her.

In this sentence, we interpret *he* as referring back to John, and *her* as referring back to Mary. In Montague grammar these pronouns are analysed as variables bound by the noun phrase denotations. But sometimes anaphoric relations arise between a term and a pronoun in different sentences, that is, beyond the sentence boundary as in (2):

- (2) A man walks in the park. He whistles.

In the anaphoric reading of (2), the pronoun *he* in the second sentence is bound by the noun phrase *a man* in the first sentence. As we know the analysis unit in Montague grammar is sentence. But we can think of (2) as having the same meaning as (3):

- (3) A man walks in the park and he whistles.

And in the framework of Montague grammar we have no problem at all to get the right interpretation of (3) translating it to the formula:

- (4) $\exists x (man'(x) \wedge walk\ in\ the\ park'(x) \wedge whistle'(x))$

which expresses also the meaning of (2).

But consider now that we can add very naturally new sentences to the discourse (2), sentences in which the pronoun *he* occurs again referring back to *a man*.

- (5) A man walks in the park. He whistles. He is Mary's friend.

If we get the meaning of the first two sentences in (5), we cannot add the third sentence and get at the same time the correct meaning of (5), since *he* in the third sentence would not be bound by the term *a man*. To get a correct translation in Montague grammar we have to know the entire discourse first. And then, consider it as a conjunction of sentences with the variables in the appropriate places. But this does not correspond very well with what intuitively seems to be the way of how we understand discourses. We do not need to know if a discourse is finished, closed in order to interpret it. We interpret sentences in a discourse, step by step, incrementally, being able to interpret new sentences as they are being said.

This kind of problems and other relatives to anaphoric phenomena as the so-called 'donkey-sentences' are the basic motivation for DRT.

II. 2. An informal description of DRT

The main characteristic of DRT is that it assumes that each sentence is provided with a representation. We will have a set of rules for converting syntactic structures into representations which are called 'discourse representation structures' (DRSs). There are two notations for DRSs. We will use the less orthodox but most used pictorial notation. First, we will describe the construction of DRSs. Let us begin with a single sentence as an example:

(6) John loves a girl.

The first step is to introduce the sentence in a box as in (7):

(7)

John loves a girl

The second step yields:

(8)

x John=x x loves a girl

From (7) to (8) first, we have introduced the *reference marker* x; secondly, we have asserted the equivalence between the proper name *John* and the reference marker x; and then, we substituted *John* for x in the sentence. All these three steps are what we have to do whenever we have a proper name.

Proper names introduce reference markers. Indefinite terms too. Thus, the next steps consist of introducing a new reference marker y, and substitute the indefinite term *a girl* for the reference marker y in the sentence, and, finally, we add the formula *girl(y)*. Thus, we build up the DRS for the sentence (6):

(9)

x	y
John=x	
x loves y	
girl(y)	

But, as we have said, DRT is not restricted to the semantics of sentences, but it takes discourse (or sequence of sentences) as the analysis unit. We have also said that in DRT, unlike in Montague grammar, we do not need the discourse to be closed, and we can interpret sentences in discourse as they are being said. Let us suppose that immediately after (6) someone adds (10):

(10) She loves him too.

We can think of DRSs as places where information is stored. Having said (10), we add more information to the DRS (9). Now, it is important to notice that anaphorically interpreted pronouns introduce no new reference markers, but make use of those reference markers available in the DRS. In this case there is no doubt: the pronoun *she* corresponds to the reference marker *y*, and the pronoun *him* to *x*. The only step, then, is to add the information that *y* loves *x*, and we will have the DRS corresponding to the discourse consisting of sentences (6) and (10), namely:

(11)

x	y
John=x	
x loves y	
girl(y)	
y loves x	

Then, in a DRS we have two types of things: a set of reference markers (in our example $\{x, y\}$), and a set of formulas ($\{John=x, x \text{ loves } y, girl(y), y \text{ loves } x\}$). The formulas in a DRS are called *conditions*. There can be atomic conditions as those in our example, or complex conditions as we will see later. Let us see now how DRSs are interpreted.

DRSs are considered as partial models of reality. In (11), for instance, as a model containing two individuals which are asserted to have some properties specified by the conditions. Now, the truth of a DRS is a relation between that partial model and a total model *M* just in case the first can be embedded in (or can be taken to be a part of) *M*.

The model *M* is defined as usual in first-order predicate logic. We define, then, the notion of *verifying embedding* of a DRS into a model *M* as a function *f* which

assigns elements of D (the domain of M) to the reference markers in the DRS in such a way that all conditions in the DRS are true in M .

A DRS is true in M if and only if there is at least one verifying embedding for that DRS in M .

Let us take DRS (11) as an example. This DRS is true if and only if there is a verifying embedding f such that assigns individuals to the reference markers x and y , in such a way that $f(x)=\text{John}$ and $f(y)$ is a girl loved by John who also loves John. It should be noticed here that the existential import of the indefinite description *a girl* is not accounted for treating it as an existentially quantified term but by the existential quantification over verifying embeddings.

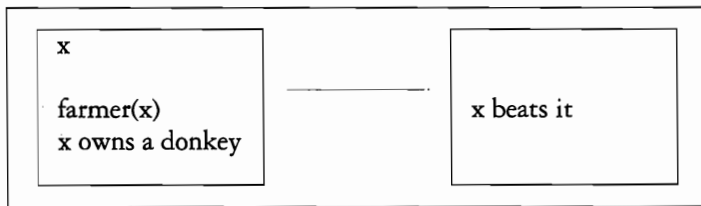
II. 3. Quantified Noun Phrases

While Montague grammar treats noun phrases (NPs) uniformly as sets of properties, DRT makes an important distinction between indefinite NPs and definite NPs. Indefinite NPs simply introduce new reference markers and atomic conditions as we have seen above. The case of definite NPs is more complex.⁶ Here we will briefly examine the case of general or quantified NPs, those containing determiners like 'every', 'each', and 'many'. Quantified NPs introduce complex conditions. Let us illustrate this with the famous donkey-sentence:

(12) Every farmer who owns a donkey beats it.

The first step in the construction of a DRS is to introduce the sentence in a box. That will be the box for the main DRS. Now, having a quantified term we have to introduce something new: the implication relation \rightarrow between DRSs. Doing that we will have:

(13)



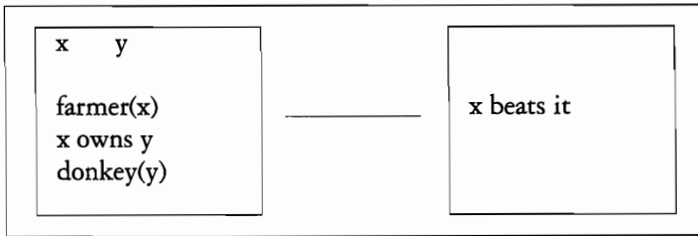
In the left box we have introduced a reference marker x , and formulas corresponding to the common noun and its relative clause. In the right box we have a formula which is the result of substituting the quantified NP in the sentence for the introduced reference marker x . In this process we have also introduced another relation

(6) Most definite NPs can be used either anaphorically or deictically. Anaphoric uses of pronouns, as we have said before, link their interpretation with reference markers already introduced by previous discourse. Deictically uses, on the other hand, link pronouns with reference markers which are contextually salient individuals. So, the information stored in DRSs is not only that conveyed by discourse, but also information given by the context and background assumptions.

between DRSs: the *subordination* relation. The two DRSs related by \rightarrow are subordinated to the main DRS; the one on the right of \rightarrow to the one on the left.

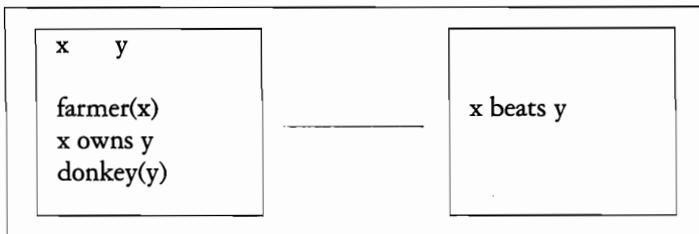
But, we can go on applying more steps for building DRSs. In the left box we can apply the rule for indefinite NPs to the expression *a donkey*. Thus, we introduce a new reference marker y , substitute *a donkey* for y in the second condition, and add an atomic condition *donkey(y)*, yielding (14):

(14)



Now, what happens with the pronoun *it* in the right box? We have said before that anaphorically interpreted pronouns are linked to reference markers available in the DRS. Now there is no reference markers nor in its DRS neither in the main DRS. So, it takes the reference marker in the left box, or specifically, in the DRS which is subordinated to. Then, we have:

(15)



Here the main DRS contains no reference markers but only one complex condition. This complex condition will be true just in case every verifying embedding for the antecedent in the condition is also a verifying embedding for the consequence.

This kind of analysis permits DRT to account for several problems related to donkey-sentences.

II. 4. Conclusions

So far, we have tried to describe some of the main motivations and features of DRT, as well as the characteristics of one of its main tools: DRSs. Finally, we want to draw out some few general remarks on this semantic theory.

DRT can be seen as a theory for overcoming some empirical problems arisen in Montague grammar. As any essay of this kind, albeit the success is clear in solving

such problems, new ones faces the new theory. In any case the step forward given by DRT is important in several ways.

Leaving aside the passing from sentence to discourse as analysis unit, first we should mention the dynamic character of the theory, which together with the representational level, makes more natural an explanation of natural language meaning and understanding in terms of a formal semantic theory of natural language. Understanding discourse, as DRT suggests us, seems to be a dynamic process of storing information (information not only conveyed by discourse but also by context and background assumptions) at some representational level. Here we can find out one of the most important values of this theory.

It should be also mentioned that, as Gamut 1991 discusses, DRT introduces a richer notion of meaning than the truth-conditional one of Montague grammar. In DRT truth is not a basic notion upon which the other semantic notions are recursively built up. Truth in DRT is a derived notion, and thus, the meaning of a discourse is not identified with its truth conditions but depends on the embedding conditions of the DRS corresponding to the discourse. Indeed, Gamut suggests, that using that richer notion of meaning we could expect to success unifying Montague grammar and DRT.

Finally, we should notice that DRT framework is not limited to the study of phenomena we have just mentioned here. DRT is used in studies of tense and aspect (see, for instance, Kamp and Rohrer 1983, Partee 1984) or propositional attitudes (Asher 1986, Zeevat 1987). It seems also worth noting that some interesting proposals have been done with the aim of treating explicitly the partiality of information in DRT as a theory of information, in such a way that on its basis could be given a right account of epistemic models and intentionality (Landman 1990).

III. Situation semantics

Although at the first moment Barwise and Perry (1983) introduced *situation semantics* as a special kind of semantic theory which would overcome problems inherent to the model-theoretical treatment of natural language meaning, developing the framework, they found the need for a general theory of information: a mathematical theory of information flow, storing and transmission which is known as *situation theory*. Situation semantics is considered now as the application of situation-theoretic tools to the study of meaning. Even we could think of different situation semantics depending on what kind of language or what fragment of what language is the object of our semantic study.

We will first introduce the concepts in situation theory necessary to understand the main features of the situation semantics we will present here.

III. 1. Situation Theory

Situations are parts of the world. My being here typing the keyboard, Mary running, yesterday's football match, me telling you "it's eleven o'clock"..., all such things are situations. They are primitive in the theory, that means, they are not

defined upon any other primitive. Human agents individuate or discriminate parts of the world as these, and guide their behavior according to them.

Information is in the world. It flows through situations. Let us examine a widely used example in order to illustrate it. Suppose a situation which consists of a cut trunk. This situation carries a lot of information: the age of the tree when it was cut, the tool use to cut it, the orientation with respect to the cardinal points,... In virtue of the different (lawlike, natural, conventional,...) relations between this type of situation with other types, our cut trunk carries information about quite different and remote situations as those we have mentioned.

The situation-theoretic tool to represent units of this information is the notion of *infor*.⁷ An *infor* is composed by a relation, a set of argument-places for the relation, an spatio-temporal location and a polarity item i such that $i \in \{1, 0\}$. Thus, the following *infor*:

(1) «runs, Mary, l , 1»

represents the information that Mary runs at the location l . On the other hand, the information that Mary does not run at l is represented by the *infor*:

(2) «runs, Mary, l , 0».

The *infors* (1) and (2) are called *duals*. We say that an *infor* s is a fact when some situation s supports it.⁸ We write $s \models \sigma$, and it is read as s supports σ , or σ is made factual by s , or σ holds in s . It is obvious that if $s \models \sigma$, then $s \not\models \bar{\sigma}$, that is, if some situation s supports an *infor* σ , then it does not support its dual $\bar{\sigma}$. Now, we cannot claim the converse, i. e., that if $s \not\models \sigma$ then $s \models \bar{\sigma}$. In other words, if some situation does not support an *infor*, we have no basis to maintain that that situation supports its dual. That means that given a situation we cannot decide about the factuality of *infors* that do not hold in that situation. Here we are introducing the partiality of information, a central notion in situation theory and situation semantics.

There are also what we call *parametric infors*. These are *infors* in which not every element is defined. In a parametric *infor*, as in a usual one, there are a relation, some argument places for that relation (among which we include the spatio-temporal location) and polarity; but instead of assigning appropriate objects for the argument-places, we parametrise them, we assign a 'label' for the argument place. Let us look at an example:

(3) «laugh, a , b , 1»

(3) is a parametric *infor*. We have labelled the role of the laughter by the parameter a and the location by the parameter b . Every assignment of appropriate objects for (some or all) the parameters in an *infor* is called an *anchor*.

(7) It must be stressed that *infors* are objects in the theory for representing units or items of information, but this does not mean that we think of them as being the real informational objects -whatever they are- which flow in the world.

(8) In one sense, we can think of defining situations on the set of *infors* it supports, and that could be useful for some purposes. But, for many important reasons (see, for instance, Barwise 1989 or Devlin 1991) situations are regarded as primitives. Thus, the primitives in the theory are situations, relations, individuals, spatio-temporal locations and polarity items.

We will see later the use of parametric infons in situation semantics. Now it is worth to establish the difference between this notion and the notion of *unsaturated* infon.

In an unsaturated infon there is neither an assigned object nor a parameter for argument-places. Nevertheless, they are considered as well formed infons. Consider the following infon:

(4) «eats, John, /, 1»

It is natural to think of 'eat' as a relation with argument-places for the eater as well as for the thing eaten (let alone the location). In (4) there is neither an object nor a parameter for the role of the thing eaten, but we can consider (4) as the information conveyed by an utterance of the sentence 'John is eating now'. So, for cases like that it is interesting to differentiate between parametrised and unsaturated infons.

We have introduced so far the two main concepts in situation theory: the situation and the infon. Let us see now how these ideas apply to the study of natural language meaning.

III. 2. Situation semantics

First of all, we have to say that situation semantics is concerned with the meaning of utterances, not of sentences of natural language. It adopts the austinian point of view considering language as action. The meaning of a sentence is an important factor, but only one factor, for determining the meaning of an utterance made by an agent addressing to some other agent in some particular circumstances. In fact, one of the main motivations of Barwise and Perry (1983) was to account for what they called the efficiency of language: the fact that one and the same expression or sentence can be uttered by different agents on different occasions to mean quite different things. Those acquainted with the classical boundaries between semantics and pragmatics will have noticed that situation semantics tries to cross over such boundaries.

Although there are some attempts to apply situation semantics to the study of the meaning of questions or commands, it is focused on the semantics of (utterances of) declarative sentences, like the two other semantic theories we have seen before.

The starting point is that utterances of sentences of, say, English are situations, where we have an speaker, an audience, and some circumstances which will affect the meaning of the utterance. As other kinds of situations, utterances carry information about other situations often quite different and remote with respect to themselves. Let us see more carefully what kind of things are involved in natural language utterance meaning.

Firstly, we have the *utterance situation*: the situation or context where the utterance is made. Let us look at an example.⁹ Suppose that Marcus says to Irina: *A man is*

(9) Not only the example but also the explanation of these concepts follow those of Devlin 1991, which differs a bit with respect to for example, Barwise and Perry 1983 or Gawron and Peters 1989.

at the door. The utterance situation u is the immediate context in which Marcus utters the sentence and Irina hears it. It includes both Marcus and Irina, the duration of the utterance, and will contain all the necessary in order to identify such things as the door that Marcus is referring to. Thus, we have that

- (5) $u \models$ «utters, Marcus, A MAN IS AT THE DOOR, l , 1 » \wedge
 «refers-to, Marcus, THE DOOR, D , l , 1 »

where D is a door that is fixed by u .

In many cases the utterance is part of a wider *discourse situation*. As we are concerned with single utterances, it will be assumed that the utterance situation and the discourse situation coincide.

In any case, the discourse situation is part of a wider situation called the *embedding situation*. We could say that the embedding situation contains the part of the world of direct relevance to the discourse. Let us take back the example to see what we mean. Suppose that the above utterance is made by Marcus as a request for Irina to open the door. If Irina acts according to the request and opens the door a change would happen in the embedding situation. That is, if e denotes the embedding situation at the time of utterance and e' the embedding situation a bit later, we would have that

- (6) $e \models$ «closed, D , l , 1 »
 (7) $e' \models$ «opens, Irina, D , l' , 1 »

We will also have (at least in many cases) the *resource situation*. Suppose, for instance, that Marcus says: *The man I saw running yesterday is at the door*. Saying that Marcus is making use of a particular situation in which he saw a man running, in order to identify the man is now referred to as being at the door. More precisely, if u is the utterance situation and M and D some individuals, then

- (8) $u \models$ «utters, Marcus, Φ , l , 1 » \wedge
 «refers-to, Marcus, THE MAN, M , l , 1 » \wedge
 «refers-to, Marcus, THE DOOR, D , l , 1 »

where Φ is the sentence

- (9) THE MAN I SAW RUNNING YESTERDAY IS AT THE DOOR.

In order to refer to the individual M , as we said earlier, Marcus makes use of another situation r occurred the day before the utterance, where there was an unique individual M such that

- (10) $r \models$ «runs, M , l' , 1 »

And, finally, there is the *described situation*: that part of the world the utterance is about. Features of the utterance help to identify which is the described situation s :

- (11) $s \models$ «present, M , l , 1 »

where l represents the location of the door at the time of utterance.

III. 3. The Relational Theory of Meaning

In the situation-theoretic framework it is assumed that the main goal of asserting declarative sentences is to convey information. As we said earlier, some lawlike relations between the rings of a tree stump and the age of the tree are what makes possible for a certain tree trunk to carry information about the age of that very tree when it was cut. The same idea is behind utterance situations. The lawlike (conventional) relationship between types of utterance situations and the types of situations they describe are what is considered meaning in natural language.

The sentence Φ : *Alfred is at the door* can be uttered by different persons to convey to different persons different information about different situations (with different Alfreds, different doors, at different times). Nevertheless, there remains an abstract relation between the type of utterances of that sentence and the type of situations described. We define the meaning of Φ as the abstract linkage $\|\Phi\|$ between two types of situations U and S such that

$$(12) \quad U = \{u \mid u \models \{\langle \text{speaking-to, } a, b, l, 1 \rangle, \langle \text{utters, } a, \Phi, l, 1 \rangle, \langle \text{refers-to, } a, \text{ALFRED, } c, l, 1 \rangle, \langle \text{refers-to, } a, \text{THE DOOR, } d, l, 1 \rangle\}\}$$

where the parameters a , b , and c stands for persons and the parameter d for doors, and

$$(13) \quad S = \{s \mid s \models \langle \text{present, } c, d, l, 1 \rangle\}$$

Thus, if we have an utterance situation u in which Marcus says Φ to Irina, then if u is of type U, there is some person, namely, Marcus, who fulfils the parameter a of the speaker. Marcus utters Φ and, in particular, utters the word 'Alfred' to refer to some individual to whom the parameter c anchors, and the expression 'the door' referring to some particular door to which the parameter d anchors. Then, we can think of Marcus as having the information that Alfred is at the door and uttering Φ for conveying this piece of information to Irina. Irina hearing the utterance will acquire the information that the situation s that Marcus' utterance is about is such that there is some particular person named Alfred who is at the door. That is, she acquires the information that the described situation s is of type S. That information is what is called the *propositional content* of the utterance. Namely,

$$(14) \quad s \models \langle \text{present, } A, l, 1 \rangle$$

where A stands for the individual referred to by Marcus as Alfred and l for the location of the door at the time of utterance. That is the information the utterance carries about the described situation s . And that is so by means of the meaning $\|\Phi\|$ of the sentence Φ , which provides the linkage between the utterance situation and the described situation, and makes possible for an utterance of Φ to be informational.

III. 4. Conclusions

We have seen which is the concept of meaning for the case of a declarative sentence. The framework may also be used for the treatment of other speech acts (See Devlin 1991). The following step would be to analyse the meanings of the parts of the sentence. At this point, it is worth to notice that no assumption on the composi-

tionality of meaning is adopted. The strategy in developing situation theory has been, from the beginning, to avoid any commitment to given methodological assumptions like this principle. At the same time, no assumption has been made about the linkage between syntax and semantics in natural language.¹⁰

Building up situation theory and semantics, notions as information, its flow, meaning and understanding are studied from the pretheoretical ground, in order to avoid problems that do not belong to the phenomena under study, but to the theory used to model such phenomena.¹¹

But some of the most interesting points for the kind of problems we are concerned with are the following ones. First, situations and relations are primitives. They are not extensionally defined in set-theoretic terms. This gives us the possibility for an interesting treatment of intensionality in a more direct and understandable way than Montague Grammar and any other set-theoretically based semantic theory.

Secondly, there is the idea of partiality. Information transmitted by natural language utterances is rarely about the whole world or complete possible worlds, but only about some small parts of it (situations). This idea of partiality as well as the treatment of truth as a derived notion in the theory is common to situation theory and DRT.

Finally, we should mention the essay of including in the theory aspects that until now had been considered as belonging to pragmatics. A respectable discipline, but which was taken as it had nothing to do with the standpoint of formal semantics. Situation theory and semantics starting from the model-theoretic semantics tradition has opened its doors to the treatment of 'formally intractable' pragmatic factors as context and circumstances. But we will take this point later.

IV. Concluding remarks

We have so far tried to present three of the most important and representative theories in formal semantics for natural language. The first one, Montague grammar, apart from the internal characteristics we have seen, shows as its most important contribution the following one, namely to propose the study of natural language meaning by means of formal tools as a respectable and fruitful line of research. Even with all its shortcomings, that is more than we usually expect from a theory of any kind.

DRT and situation semantics came (almost at the same time) to go beyond the problems arisen in Montague grammar and brought new perspectives in the study of natural language meaning. With DRT, we passed from sentence to discourse, and it was introduced a dynamic view which corresponds more closely to the idea of what understanding is. The explicit treatment of partiality (present implicitly in DRT), and the information-based explanation of what we *do* when we use language in

(10) In Gawron & Peters 1989 and Pollard & Sag 1987 lexical-functional grammar and head-driven structure grammar are, respectively, used as syntactic theories for situation semantics.

(11) This point is involved in the adoption by situation theory of Peter Aczel's non-well-founded set theory instead of ZF-set theory.

everyday communication are the most essential contributions made by Situation Semantics.

The variety in terminology, notations and formal mechanisms in the three theories may have confused the reader, making difficult to see the similarities and differences among them. This confusion will be more dramatic for that who is seeking for *the right* semantic theory. How are we going to unify so (at least apparently) different theories? This seems to be a very natural question for the people believing in one true theory for each research topic. In fact, there is also a general trend for preferring unified and general theories. We could mention several points to take in mind in order to try to answer the question above.

The first one is related to a general discussion in linguistic theory: conceptualism versus realism. Conceptualism is the view according to which meaning —and all relevant aspects of language, from a linguistic point of view— has to do with a mental system. This need not more explanation for the reader acquainted with chomskyan syntactic theories. Realism, on the other hand, takes meaning as related to language and reality — it does not claim that mind has nothing to do with language but it does not bother studying it. While conceptualist semanticists and, generally, syntacticians adopt conceptualism, the tradition in formal semantics is realist. In fact, it is difficult to see Montague grammar as an explanation of meaning as a psychological matter. Barwise and Perry also take realism as an assumption of Situation Semantics. But, as we have said earlier, one of the advantages of DRT is that it can be seen as a bridge between these two (apparently) opposite approaches. We could find here a way for overcoming the dispute, just avoiding it.

Another point has been suggested earlier. We could maybe enrich the notion of meaning present in Montague grammar (truth-conditional meaning) by a dynamic notion as the one in DRT and use a dynamic logic to integrate both theories, as Gamut 1991 does. It remains to be seen the success of such a move, and whether it will be also useful for the case of situation semantics. It seems also quite natural to think about a possible approaching between DRT and Situation Semantics, given their common characteristics like the dynamic nature of meaning, partiality of information, and the inclusion of contextual factors. This attempt of convergency is what reaches a paper like Cooper and Kamp 1991.

Taking the three theories from a general standpoint, one of the most remarkable points is the 'pragmatic turn in semantics' caused by DRT and specially by Situation Semantics. It seems a fact that trying to give account for meaning in natural language has broken the limits imposed by logic (not only first-order logic but also those most sophisticated as Montague's intensional logic) on the notion of meaning as truth-conditional, static —immune to context changes—. The boundaries between semantics and pragmatics are fuzzier than ever, and the very idea of logic has become much more vague than the most condescending Quine would be near to imagine. Someone would have to clarify what is going to loose in such a 'pragmatic turn'.

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