Article

"Syntactic Analysis and Semantic Processing"

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SYNTACTIC ANALYSIS AND SEMANTIC PROCESSING

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Much of the current effort in artificial intelligence is directed towards defining the semantic relationships between the parts of a sentence in order to obtain access to the meaning (or the information) contained in the sentence. One widely used technique is the incorporation of detailed semantic properties of individual words in their lexical entries; these properties refer to certain general features of the world (human, abstract; liquid, solid; inherently long, inherently short; etc.), general relationships (larger than; part of; inside of; etc.), actions in general (move, transfer, etc.), case relations (actor, agent, goal, etc.) and so on.

My purpose here is to show that it does not seem possible to avoid carrying out a detailed syntactic analysis of the sentence if one wishes to apply a semantic system, of whatever sort, for further processing. Such a complete syntactic analysis turns out to be necessary in order to avoid mismatching parts of the sentence, for such mismatching would vitiate subsequent semantic processing. Thus, we do not wish the analyzer to furnish sentence decompositions in which sequences appear containing a singular subject and a plural verb, or vice-versa: **John eat meat*; **The men eats meat*. It may be that semantic processors will one day account for such number agreement, but, as we shall see below, there remain quite complicated problems of subject-verb agreement in the case of coordinate structures, so that a full syntactic parsing is necessary. We shall also find that the unacceptable decompositions of sentences furnished by the analyzer serve as indicators of just where semantic data should be incorporated in the processing system.

When it is possible to obtain coherent syntactic analyses, these can be examined in order to ascertain how to include further semantic relationships

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that may enable one to eliminate those syntactically justifiable analyses which nevertheless contain semantically incoherent sequences.

Finally, we shall see that certain relationships between words are arbitrary, in that they have been conventionalized in a given domain of discourse. In this case, neither syntax nor semantics can help us choose the appropriate relationship.

1. **Use of Syntax**

Let us consider the following sentence:

(1) An account of the details of locomotion and postural support in such animals and associated deficits in righting, orienting, eating and drinking is not possible...

(Proceedings of the National Academy of Sciences, vol. 78, No. 5, Mai 81, p. 3280)

If I denote the subject by *Sb,* pieces of the subject by *Sb i,* and the successive noun phrases in the sentence by N_1, N_2, etc., then the analyser might get, in a first pass through the sentence, the following decomposition for *Sb*:

(2) $Sb = Sb_1$ and Sb_2 and Sb_3 and Sb_4
where $Sb_1 = N_1$ of N_2 of N_3 ; N_1 = An account, N_2 = the details, N_3 = locomotion
$Sb_2 = N_4$ in N_5 ; N_4 = postural support, N_5 = such animals
$Sb_3 = N_6$ in N_7 ; N_6 = associated deficits, N_7 = righting, orienting, eating
$Sb_4 = N_8$; N_8 = drinking

The verb *is*, however, is singular, and so the analyser rejects this decomposition. Whatever the system of syntactic (or semantic) analysis, it is clear that the procedure of detaching the pieces of *Sb* one by one so as to reach a singular subject (*account*) will be long. Nor is there any hope of a shortcut. Since the analyzer cannot "know" which decomposition will be the right one until it has been constructed and tested against the verb, the analyzer must try all possible combinations. Hence, it will also try the following ones, among others:

(3) $Sb = Sb_1$ and Sb_2 and Sb_6 ; $Sb_6 = Sb_3$ and Sb_4 ;

(4) $Sb = Sb_1$ and Sb_5 ; $Sb_5 = N_4$ in [N_5 and (N_6 in N_7 and N_8)] ; etc.

None of these decompositions are acceptable, of course, since the subject is plural and the verb *is* is singular[1]. Nor is there any use in scanning the sequence of words preceding *is* and picking out the singular nouns (*account, locomotion, support* and the gerunds); even if one chose the right one as subject, the complete structure of the subject must nevertheless be computed and so made available for later semantic processing. Furthermore, even if the correct singular noun could be chosen, we cannot guarantee that *is* is in fact the verb of the sentence structure without carrying out the full syntactic analysis of the sentence.

There is thus no avoiding the difficulty of carrying out the syntactic analysis of this sentence in order to obtain the correct decomposition of the subject, viz.:

(5) Sb = An account of the details of [N_3 and (N_4 in N_5) and (N_6 in N_7 and N_8)]

The program cannot currently obtain the correct analysis, in which (*N_3 and N_4*) is a conjoined noun phrase, modified by *in* N_5[2].

In the following sentence, we see that a certain syntactic structure can in fact appear in two different places in the grammar; one of them leads to an unacceptable decomposition:

(6) The disintegration of this molecule, carrying a net positive charge, and subsequent emission of radiation registered on the oscilloscope.

In the acceptable analysis of this sentence, the subject is a conjunction of two noun phrases: *The disintegration of this molecule* and *subsequent emission of radiation*, in which *this molecule* is modified on the right by the string containing a present participle, *carrying a net positive charge*.

Another decomposition is possible, and will be found by the analyzer, namely, the one in which the subject is a conjunction of three strings: the

1. There are exceptions, of course, to the number constraint between subject and verb, as in the following sentences:

(i) Too many cooks spoils the broth.

(ii) That he left and that no one noticed it is incredible.

Proverbs like (i) will present difficulties, but sentences like (ii), with sentential subjects, can be handled without any problem in the framework of syntactic parsing.

2. The problem is that a conjoined noun phrase, e.g., *GN and GN*, would be required in the grammar to obtain this analysis. Such a conjoined noun phrase is a rather complicated object to handle, so that it would be better, at first, to omit it from the grammar.

noun phrase *the disintegration of this molecule*, the gerund string *carrying a net positive charge* (conjoined to *the disintegration of this molecule* by a comma), and *subsequent emission of radiation*. The gerund string is seen in such sentences as

(7) Carrying a net positive charge induces the formation of...

That is, such a gerund string can be a subject of verbs like *induce, cause*, etc., but not of *register*:

(8) *Carrying a net positive charge registered on the oscilloscope.

Since this gerund string is a possible subject of certain verbs, the only way for the analyzer to rule out this second, unacceptable decomposition is on the basis of a classification of the verbs in the lexicon according to their accepting (or not) a gerund subject. Thus, *induce, cause,* etc., are marked as taking the gerund subject, but *register, hesitate,* etc., are not so marked. A restriction on the verb checks this compatibility, and in the case of the unacceptable decomposition under discussion, rejects the latter.

It might seem that the conjunction of a noun phrase and a gerund string is not possible, since unlike entities cannot in general be conjoined. But this is not the case, as we see in sentences like the following:

(9) Restructuration of the lattice, transporting free electrons along its axis, and elimination of the positron excess will promote...

In the following sentence, an unacceptable decomposition can be ruled out quite simply on the basis of syntax, but would be much harder to treat on a purely semantic basis:

(10) We see the process leading to the coupling of translational energy and vibrational energy is radiative.

The decomposition that reflects the intention of the writer of this sentence contains a complement clause as object of *see: the process... is radiative*. A second decomposition can be reached by the analyzer, one containing a conjunction of two sentences, S_1 and S_2:

(11) a. S_1 = We see the process leading to the coupling of translational energy.

b. S_2 = Vibrational energy is radiative.

In this decomposition, the object of *see* is a noun phrase, *the process leading to...* It would be difficult, on semantic grounds, to formulate a rule disallowing S_2; indeed, the question of whether S_2 is semantically deviant or not is not a simple one for a non-physicist. The following sentences are acceptable:

(12) a. A black body radiates energy.
b. Energy radiates from the black body.
c. The energy is emitted by radiation.
d. The process is radiative.

But whether S_2 is acceptable or not, i.e., whether vibrational energy can be radiative or not, can only be decided by asking a physicist.

Fortunately for us, our task is much easier if approached *via* syntax, for S_1 is unacceptable on syntactic grounds. S_1 contains the noun phrase *coupling of translational energy* which is an unacceptable nominalization of the verb *couple*. This latter appears with two noun phrases connected by *to*, and the preposition *to* commutes with *and*:

(13) a. We coupled A to B = We coupled A and B.

The sentence with only one noun phrase is unacceptable:

(13) b. *We coupled A.

There are many verbs behaving like *couple*, with respect to the commutation of the preposition in the object with *and* and the unacceptability of just one noun phrase in the object. These verbs constitute a syntactic class, and are noted in their lexical entries as belonging to this class. The nominalization of *couple* yields *the coupling of A to B* or else *the coupling of A and B*, but **the coupling of A* is unacceptable. Hence S_1 is ill-formed and will be rejected by the analyzer on these syntactic grounds.

A final example provides an instance where the unacceptable decomposition cannot be disqualified on semantic grounds but only for rather pragmatic syntactic reasons. Consider the sentence

(14) a. In the sample, accurately weighed, specimens were found which...

The sequence, *accurately weighed*, is a modifier of *sample*. However, if we remove the second comma, we obtain the following sentence

(14) b. In the sample, accurately weighed specimens were found which...

in which the sequence *,accurately weighed* can no longer be a modifier of *sample*. Since both sentences are identical from the beginning until *weighed*, there is no reason for the analyzer not to try, in the second sentence as well, the branch of the grammar in which *,accurately weighed* is parsed as a modifier of *sample*. This reading can be rejected only on the rather pragmatic syntactic ground that, in this position, a modifier of *sample* beginning with a comma must also end with a comma.

2. Use of syntax and semantics

We have seen in one of the sentences discussed above, the need for establishing sub-classes of the major grammatical categories: adjectives, nouns, verbs, etc. By establishing a certain sub-class of verbs that accept a gerund string as subject, we were able to disqualify a gerund string as subject for a verb not classed in that sub-class, since it yields an unacceptable sentence. This procedure can be extended, and leads to a simple, effective and yet quite powerful incorporation of semantics directly into the syntax.

Consider the following sentence:

(15) A fundamental problem in the theory of several complex variables is relating the boundary of holomorphic functions to the geometry of the boundary.

(Proceedings of the National Academy of Sciences, vol. 78, No. 7, Juillet 81, p. 3998)

There are two interesting difficulties to be met in the analysis of this sentence. The subject is *problem*, and in a first try the verb may be taken as *is relating*, as in *He is relating the story to them*. However, in this use of *relate*, the subject must be human: **The problem is relating a story to them*. Since *problem* is not a member of the semantic noun sub-class "human", the analyzer rejects this use of *relate*.

In a second try, the program can choose the second entry for *relate*, which is similar to *couple*, as discussed above in (13):

(16) [We, The theory] relates A to B = [We, The theory] relates A and B

These sentences can indeed occur in the progressive: *We are relating A to B*, however, if the subject is a "sentential" noun like *theory* or *problem*, the progressive occurs only under special conditions in which the theory is under immediate discussion. These conditions do not generally obtain in a written article such as the one from which the sentence was abstracted, and so this decomposition can be considered unacceptable, i.e., the one where the subject is *problem* and the verb is *is relating*.

Another possibility for the analyzer is to take the sequence beginning with *relating* as a gerund object of *be*. In this case, if the subject of *be* is a noun phrase, the noun must be a "sentential" noun like *fact*, *problem*, *difficulty*, etc.:

(17) a. The difficulty here is relating A to B;
b. *The (support, limit) is relating A to B.

This decomposition is therefore acceptable, and reflects the meaning intended by the writer: the subject is *problem* the verb is *is*, and the object of *is* is the gerund *relating A to B* where *A* = *boundary...*, and *B* = *geometry...*

The reader will note the mixture of syntax and semantics that was required to solve the problems encountered in the course of analyzing this sentence. We distinguished the two meanings of *relate* by the sub-class of acceptable subject for each usage, and the sub-class of acceptable objects. Then, we noted that the progressive tense on *relate* was not generally acceptable for the particular sub-class of its subject.

This method of including semantics in the syntax *via* the sub-classes is very general and increases the power of the syntactic parser considerably. It is specified in the lexical entries of the verbs what (semantic) sub-classes are acceptable as subject, object or indirect object. During the parsing, the analyzer can consult the lexical entries of the words of the sentence and verify whether a verb contains, in one of these positions, a noun belonging to an unacceptable sub-class. Thus, when analyzing the sentence

(18) The rotating field theory predicts that...

the participle *rotating* will not be taken as an adjective modifier of *theory*, as *dining* modifies *gentlemen* in *The dining gentlemen were...* The parser checks whether the noun is an acceptable subject of the verb of the *V-ing*; this is true of the pair *gentlemen-dine*, but certainly not of *theory-rotate*:

(19) Gentlemen dine; *A theory rotates.

This parse is rejected, and *rotating* is analyzed as an adjective on *field*.

Verb and noun sub-classes are sometimes defined with respect to each other. In such a situation, the syntax and the semantics are enmeshed, so that it is hard to say where the one ends and the other begins. Consider, for example, the class of collective verbs, say *Vcoll*, defined as taking only a plural noun in its noun phrase object:

(20) a. Max [collected, dispersed, amassed,...] [the chairs, the men]
b. *Max dispersed the chair.

However, a certain sub-class of singular nouns can occur with *Vcoll*:

(20) c. Max dispersed (the furniture, the information, the gentry)

These nouns belong to the sub-class *Ncoll*, and they are defined with respect to the pre-existing sub-class of verbs, *Vcoll*.

Consider now the following sentence:

(21) Our hypothesis concerns the current which disperses the iron atoms and its relation to the electromagnetic field.

The desired parse shows a conjunction of two sentences:

(22) $S = S_1$ and S_2
S_1 = Our hypothesis concerns the current which disperses the iron atoms
S_2 = (Our hypothesis) (concerns) its relation to...

The parentheses indicate the reduction of the enclosed words to zero after the conjunction.

Another decomposition is formally possible, in which sentence conjunction occurs under the scope of *which*, i.e., in the relative clause:

(23) S = Our hypothesis concerns the current [which disperses the iron atoms and (which) (disperses) its relation to...]

This analysis is unacceptable because *relation* is not in the sub-class *Ncoll*, hence is an unacceptable singular noun object of *disperses*.

3. Neither syntax nor semantics

There are of course sentences where neither syntax nor semantics can be of use in resolving the ambiguities encountered during the parse; recourse must be had to the particular semantics of the domain under study. These problems are particularly difficult when the sentence contains several conjunctions, as most sentences in scientific writing do.

Consider the following sentence:

(24) DNA fragments ... have been isolated by digesting plasmid pCB3 DNA with appropriate restriction endonucleases, separating fragments by gel electrophoresis on 1% agarose or ... acrylamide gels, and recovering DNA fragments from the gel.

(Proceedings of the National Academy of Sciences, Vol. 78, No. 5, Mai 81, p. 2767)

The first difficulty arises in parsing the prepositional phrase by digesting plasmid pC. Two analyses are formally possible here, viz., parsing digesting as a participial adjective or as a gerund. This yields:

(25) a. digesting plasmid = plasmid digests (something)
(similar to: running water = The water runs)
b. digesting plasmid = (something) digests plasmid
(similar to: electrolyzing water = (something) electrolyzes water)

However, in the domain of molecular biology, it is known that restriction endonucleases digest plasmids, whereas plasmids do not generally digest anything. Note that both analyses in (25) are semantically plausible, since *digest* here does not have its usual meaning, but rather something like *break up into smaller pieces by a process resembling digestion*. With such a meaning of *digest*, one cannot guess which of the plasmid and the endonuclease digests the other. What is needed here is the establishment of appropriate noun sub-classes for the domain, which accompany particular sub-classes of verbs as subject or object; cf. the work of N. Sager and collaborators.

Next, the analyzer parses the sequence *separating fragments* as a right modifier of *endonucleases*, as it is of *machines* in *Machines separating fragments are useful*. Continuing, the analyzer attaches *and recovering*

DNA fragments as a conjunctional string on this right modifier of *endonucleases*; this would be correct for *Machines separating fragments and recovering fragments are useful.* The problem is similar to the first one discussed: how can the analyzer know whether *endonucleases* is an acceptable subject for *separate* and *recover*? Specific knowledge of the semantics of the domain of study (molecular biology) is required, and this knowledge must be organized in terms of the appropriate sub-classes for the subject and object of the verbs in the domain.

Even if we manage somehow to disallow *separating fragments* as a right modifier of *endonucleases*, we immediately encounter another problem when the parser attaches *separating fragments* as a noun phrase to the noun phrase *endonucleases*, i.e., the digesting is done with endonucleases and with separating fragments. Here we encounter the adjective-gerund problem a second time in the noun phrase *separating fragments*. Is *fragments* an acceptable subject of *separate*, or must this sequence be parsed as a gerund?

Continuing in this way, we see that the analyzer will encounter the same problem a third time in the sequence *recovering DNA fragments from the gel*, which also presents the adjective-gerund ambiguity. Whatever the solution adopted, note that the problem is quite clearly circumscribed from the grammatical point of view, i.e., from the point of view of the construction of the grammar: what are the acceptable sub-classes of nouns for the verbs of the domain? This is the question that must be answered; it is a semantic question, but it can be formulated in terms of the syntax, which is in any case required.

Since this question is semantic, it is of course highly sensitive to the domain in which it is posed; a given verb may well have different acceptable sub-classes in some syntactic position in different domains of discourse. Thus, in the domain of general English, we observe the following acceptabilities:

(26) a. The leader has a message (for the people).
b. *The message has a leader.

But in the domain of molecular biology, *message* and *leader* belong to quite different sub-classes, i.e., their meaning is different, hence their relationship to *have* is different. In this domain, *message* is not an abstract noun, as it is above in general English, but a concrete noun: a genetic

message consisting of a sequence of atoms. Similarly, *leader* is not a "human" noun, but a concrete noun meaning a sequence of atoms. And this is how we find these words used in texts in molecular biology:

(27) This message has a leader of approximately 50 nucleotides.
(Proceeding of the National Academy of Science, Vol. 78, No. 5, Mai 81, p. 2930)

But note that the usage in any domain, viz., the assignment of *message* to the sub-class of "concrete" nouns, is arbitrary, and is fixed by the conventions of the domain, not necessarily by syntax or by semantics. Hence, neither syntactic nor semantic processing, of whatever sort, could possibly determine the relationship between *message* and *leader* in the domain of biology, nor could it discover that in this field plasmids are usually digested. These usages have been fixed by convention among the scientists working in the field; they would constitute lexical entries, much as it must be noted in the general lexicon on English that *have* is a verb, *science* is a noun, etc. Now, it may be argued that such conventional definitions of words, in a particular domain, can simply be regarded as the semantics of that domain; thus, *digest* has one semantics in general English, and another in the sub-domain of molecular biology. This is true, but it amounts to begging the question, namely, who will do the semantics of molecular biology? Linguists and molecular biologists don't generally know much about molecular biology and linguistics, respectively. In that case, it will have to be the linguist who will ferret out the semantics of molecular biology, in collaboration with willing molecular biologists. The linguist now faces the problem of what questions to ask the molecular biologist; but since the linguist has no special knowledge of the domain, he doesn't know which are the important questions. However, if the linguist first attempts a syntactic analysis of the text to be manipulated (for translation, or for resume, or whatever), the questions appear in the output.

Many of the difficulties with the semantics of unfamiliar combinations, like *digesting plasmids* above, become especially acute when a sequence headed by a conjunction is to be parsed. Consider, for example, the following sentence:

(28) The third body is necessary for conservation of energy and momentum in the recombination process.
(Journal of Chemistry Physics, Vol. 33, No. 4, Oct. 1960, p. 1202)

Three analyses, at least, will be furnished by the analyzer. In the first, momentum is conjoined to energy:

(29) a. conservation of [energy and momentum] in the recombination process.

This analysis refers to the conservation of two things, and *in the recombination process* modifies *is necessary*. In the second analysis, *momentum* is conjoined to *for*:

(29) b. for [conservation of energy] and (for) [momentum in the recombination process]

In this analysis, the third body is necessary for two things: conservation and momentum. The third analysis shows a conjunction of two sentences:

(29) c. $S = S_1$ and S_2
S_1 = The third body is necessary for conservation of energy
S_2 = Momentum (is) (necessary) in the recombination process

In this analysis, *is necessary* has been deleted under the conjunction *and*.

If now we grant that the semantics of all the nouns involved here is known, it is not at all clear how this semantics can be used to determine which analysis represents the intention of the author. Is momentum necessary in the recombination process (third analysis), or is there momentum in the recombination process (second analysis)? In fact, it is the first analysis that is intended: both energy and momentum must be conserved in certain processes. It is not at all clear how the inclusion of semantic relations in the lexical entries of this domain would allow us to choose the first analysis over the others.

4. Conclusions

The examples I have discussed above provide some indications of how it might be possible to incorporate semantics into text analysis. It seems necessary to decompose the process into two steps: first the syntactic analysis should be carried out, and, if done correctly, it assures us of having only syntactically coherent decompositions as the results of the parsing phase. In a second step, we can use appropriate sub-class information in order to eliminate any semantically incoherent analyses. This semantic information about noun sub-classes, verb sub-classes, etc., is contained in

the lexicon. The importance of this second step — the use of semantic sub-classes — has been recognized of course by workers attempting to set up semantic networks. Thus Schank (1975, p. 13) says: "... if ... an elemental syntax established that 'car' is the subject, then there are only a small number of things that can be said about a car. We probably will not hear that the car decided to hop up and down and yell for its mother." That is to say, the sub-class of *car* is not acceptable as the subject of *hop* or *yell.*

Proponents of semantic networks have a more ambitious goal than that of merely setting up various sub-classes in the lexicon. A whole network of relationships between the words of a given domain must be set up, and it is hoped that these relationships will be the decisive ones for extracting the meaning from the text. From a practical point of view, it is most unlikely that such a network will ever be set up for any scientific domain of interest. The scientist, whether molecular biologist, physicist..., cannot be bothered to devote his time to such an unrewarding linguistic project, and the linguist literally cannot discover these relationships without the help of the scientist. Hence any practical application of a semantic system based on such extensive networks seems most unlikely indeed.

However, it is precisely here that syntactic analysis may be able to come to the help of the semanticist (and vice-versa!) by furnishing him with the material necessary for the construction of such a semantic network. Firstly, a full syntactic analysis can save us time and effort in semantic processing, as we saw above in connection with the decomposition (11). This unacceptable decomposition can be eliminated on purely syntactic grounds, without going into the question of how to show that the decomposition *energy is radiative* is semantically incoherent.

Secondly, the analyses furnished by a detailed program of syntactic analysis, we have seen above, highlight precisely the relationships that must be explicitated (particularly in the lexicon) in order to eliminate those analyses which are semantically incoherent[3]. The most important of these relationships turn out to be those related to a verb: its subject, object, or indirect object. In order to do any semantic processing, it must be known what sub-classes of nouns are acceptable in each of these positions for every

3. For a detailed program and grammar of English, cf. Sager (1981); for French, cf. Salkoff (1973, 1979).

verb of interest. This, incidentally, is what is done when a semantic network is set up: the restrictions on the kinds of nouns that can occupy different positions, or case "slots", with respect to the verb are similar to the subclass restrictions under discussion here. But if the syntactic analysis is done first, then the linguistically appropriate material is made available for semantic processing. Thus, in sentence (1), it is only after a rather long and complicated syntactic analysis that the correct subject (*account*) appears in the output. This example is from general English; when it becomes necessary to process text from some unfamiliar scientific domain, the linguist, on the basis of the decompositions furnished by the analyzer, will know just what questions must be asked of an expert in the field so that semantically bizarre-looking analyses can either be justified or eliminated.

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Résumé

L'auteur examine diverses difficultés qu'on rencontre lors de l'analyse automatique d'une langue naturelle. Il montre qu'une analyse syntaxique détaillée permet de détecter et d'écarter des analyses incohérentes du point de vue de la syntaxe sans devoir recourir à la sémantique. Ensuite, certaines analyses syntaxiquement bien formées, mais incohérentes sur le plan sémantique peuvent aussi être écartées en incorporant la sémantique directement dans la grammaire, sans construire un composant sémantique indépendant. Ceci peut être fait au moyen de règles de sélection verbales fines et d'une classification lexicale détaillée basée sur ces règles de sélection. Si les difficultés qui subsistent ne peuvent pas être traitées par ces deux méthodes, elles ne peuvent non plus l'être au moyen d'un composant sémantique autonome.