IMPLEMENTING COORDINATION IN A DEPENDENCY GRAMMAR TO IMPROVE HUMAN - MACHINE DIALOGUE

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1. Introduction: DG coordination in human-machine dialogue

1.1. What syntax for coordination?

The syntactic structure of coordination is a vivid subject of debate, in both phrase structure grammars and dependency grammars. The latter may either incorporate solutions adapted to their formal idiosyncrasy or adapt the analysis used by phrase structure grammars. (Jarvinen, & Tapanainen, 1998; Hudson, 1990). Dependency Grammar models (DG) are an alternative to phrase structure grammars (PSG) and are currently employed for industrial applications. One of these models is Meaning – Text Theory (MTT) (Melc'uk, 1988), which has been extended, (Kahane, 1996; Lison, 2007) with the purpose of increasing its expressive power and dealing with several linguistic phenomena which are problematic in dependency grammars. According to Jarvinen, & Tapanainen, 1998), coordination is one of these phenomena, and its representation in DG requires some constituency information.

Representing coordination of constituents in dependency grammars (Tesnière, 1959) or MTT also seems to be problematic, even for enriched versions like Kahane's (2003) PUG (Polarized Unification Grammar). DG representations are supposed to be order-independent, but current analyses for coordination of constituents do not fulfill this property. As a consequence, coordination of phrases represents a major problem for DG models using only dependency information.

It seems indeed that some structures fit better into DG / MTT than others. In fact, subordination structures are easily integrated, since the hierarchical relationship between a subordinate and a matrix sentence parallels the head-complement or head-adjunct relationship of governor - governee. Coordination, by contrast, does not hold this kind of relationship, since conjuncts are at the same level, and neither of them is dependant on the other.

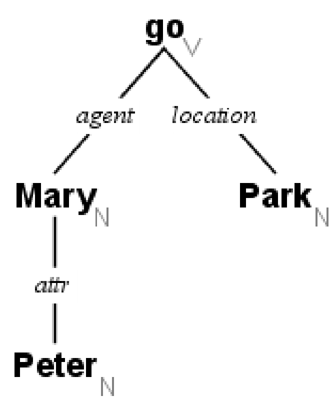
Coordination of sentences can avoid this lack of parallelism with the governor - governee relationship, since the conjunction may be represented as the head of the conjuncts.

Nevertheless, a problem appears in the representation of coordination of constituents, as is shown in Example (1). In this example, the head of the phrase “Peter & Mary” must be a noun, to satisfy the subcategorization requirements of the verb, which requires a noun phrase as its subject.

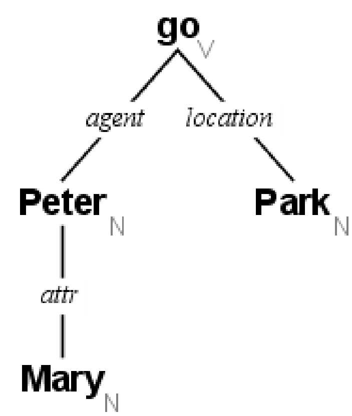
(1)a Peter & Mary went to the park.

(1)b Mary & Peter went to the park.

In order to deal with these cases, the second conjunct is often analyzed as a dependant of the first one (Jäarvinen & Tapanainen, 1998). This is represented by figure 1. If the order is reverted, the resulting representation will be slightly different, as in figure 2:



(figure 1) Graph for “Mary and Peter went to the park”



(figure 2) Graph for “Peter and Mary went to the park”

According to MTT principles, word order variations that do not affect the actantial structure of a verb should not be present in the representation of the semantic structure, since the information provided by this different word order is not semantic, but belongs to the information structure level (Mel'cuk, 1998). Therefore, there should be a unique semantic representation for the formulations (or “texts”) (1)a and (1)b, which is neither (figure 1) nor (figure 2).

This idea of equivalency between a single semantic representation and different textual formulations that is behind the MTT model can also be enlarged, so that the same semantic representation stands for formulations of it in different languages. Therefore, sentences having the same meaning, like the examples in English, Spanish and French in Example (2), should also share a single representation.

(2) a Peter and Mary went to the park.

(2) b Pedro y María fueron al parque.

(2) c Pierre et Marie sont allés au parc.

1.2. Industrial application: VirtuOz human – machine dialogue

The capacity of matching one single semantic representation with a multiplicity of formulations and languages may be usefully employed for industrial NLP language recognition applications. This is the case of the firm VirtuOz, which makes use of MTT for language recognition in human – machine dialogue. VirtuOz' computational grammar consists of a MTT implementation inspired by Kahane (2003, 2006). The formalism, denominated PUG[1] (Polarized Unification Grammar) is an enriched version of MTT with a number of formal innovations, but not including information about phrase structure.

This computational grammar allows VirtuOz to handle its human-machine dialogue system with the following mechanism: On the one hand, conversational agents' databases contain a series of tree representations (graphs) of possible human utterances, organized in prototypical conversations, and associated to answers or actions. Human utterances, on the other hand, are parsed in real time and transformed into syntactic and semantic tree representations of the same kind. Language recognition is then based on the matching of human utterance graphs with the graphs stored in the agent database. In this system, language recognition performance depends on the generation and matching of good semantic graphs. In order to match, graphs need to be identical, or similar to a high degree.

Current DG analysis of non-sentential coordination in VirtuOz databases encounters the problem mentioned above: one conjunct is represented as the head of another one. This is illustrated by (figure 1), and the resulting analyses are therefore dependent on word order. As a consequence, sentences required for the language recognition system and which includes coordination must be stocked at least twice in the databases in order to recognize the two different word orders of coordination (except for the coordination of sentences, which are order-independent). In this case, the theoretical inadequacy of current analyses is responsible for superfluous human work in an industrial application.

This paper presents a new analysis for coordination of constituents in an extended version of Dependency Grammar and the Meaning-Text Theory. It presents a construction for the coordinate conjunction, and shows how it can be integrated in a whole computational

[1] The PUG acronym is the English translation of the French original GUP (Grammaire d'Unification Polarisée)

grammar without regressive effects. Regression is indeed one of the greatest problems when making any modifications or additions in a computational grammar that is currently in use. When adjustments are made, the resulting analysis of the utterances concerned by the modification will change, and this change may be fatal for industrial implementations of MTT as VirtuOz'. After the modification, human utterance graphs would no longer match with the graphs stored in the database prior to the change, and these utterances will not be recognised. It is therefore vital to preserve the stability of the analyses when making any modifications in a computational grammar. This paper also illustrates how to avoid regression affects when integrating new constructions in an operative computational grammar.

The language recognition system created by VirtuOz has been successfully used for human – machine dialogue since 2003. Its virtual agents are present in several countries, and are present on the websites of numerous firms, such as SFR, SNCF, eBay, PayPal, or Fnac, where they provide information, advice, or assistance. They aim to improve the user experience online and to reduce operational and support costs. Nevertheless, these virtual agents encounter the problem mentioned above concerning coordination: one conjunct is analyzed as a dependant of the other. In consequence, the analysis is order dependent, which increases human workload in industrial applications.

In order to deal with the coordination problem without causing the system to regress, a copy of the VirtuOz agent databases was used as a platform for research. First, the constructions necessary for dealing with the different kinds of coordination were implemented in VirtuOz test databases. Second, a corpus of 50-80 utterances representative of the diversity of coordination types were parsed with both the old and the new constructions, and the results were compared. And third, all the utterances in the virtual agents' databases containing coordination were extracted and analyzed with the old and new constructions.

These three steps correspond to three stages of implementation of the constructions for coordinate conjunction; the first step presents the new construction, whereas the second allows us to check if the new constructions are more efficient than the former ones. The third step provides a means for guessing how many and which utterances must have their analysis updated in the databases after the integration of a new construction. This paper concerns only the implementation and integration of constructions for coordinate conjunctions in VirtuOz' English grammar, though this study has also been achieved for the Spanish and French databases with similar results.

For this study, a corpus in English was created out of 30,292 user entries from dialogue with a virtual agent. In this corpus, 1,341 user utterances contain the conjunction

« and », which constitutes 4.4 % of the user entries. This percentage increases to 6 % if we consider only the utterances of more than one word. By contrast, the complementizer « that » appears only in 2.5 % of this corpus. These data show that coordination is a non-negligible phenomenon that should be considered and optimized in the grammar.

This paper focuses on constituent coordination; it presents the different types, as well as an overview of the most important analyses which have been proposed for them in dependency grammars. Then, it exposes the particularities of the GUP, the version of MTT / DG where this analysis for coordination has been implemented, and explains the construction proposed for analyzing the coordinated conjuncts. Finally, it gives details concerning the metrics which show the advantages of the new constructions and the process of integration of these constructions in the grammar to avoid regression.

2. Task: What constituents can be coordinated?

Sentences (3) and (4) illustrate two different kinds of coordination, namely coordination of constituents and coordination of non-constituents. The first one coordinates phrases or lexical items and is highly frequent, whereas the second one, rarer in the corpus, contains a conjunct which is not a single constituent phrase and can be analyzed as elliptical:

(3) Peter & Mary went to the park.

(4) A payment went out of my bank yesterday and one ___ today.

Only the first type will be considered here. Coordination of non-constituents goes beyond the scope of this paper, and will be left for further work.

In DG, it is heads, and not phrases which are coordinated. They are usually of the same category: nouns (5), adjectives (6), adverbs (7) and verbs (8). Coordination of prepositions (9) is rare, and there are no examples in our corpus. By contrast, prepositional phrases are often coordinated (10)[2]. Two or more items may be coordinated, but the only case of multiple coordination found in our corpus is coordination of nouns.

(5) What is your sort code and account number?

(6)[3] I'm getting rude and crude emails.

(7) How To Lose Weight Fast and Safely?

[2] Prepositions are analyzed in VirtuOz' GUP as dependants. Coordination of PP amounts then to a coordination of preposition-marked SNs.

[3] Coordination of modifying nouns can receive the same treatment, as in "*What is in the fashion and accessories section?*"

(8) You have charged me and I want to know what for.

(9) Spanair will offer more than 3.500 scheduled flights *from and to* Ibiza.

(10) I want to pay a purchase on eBay from my bank account and not from my credit card.

Some cases of coordination may be syntactically ambiguous (11), since several analyses are available. In (11)a the coordinated heads are *impact* and *options*, whereas in (11)b the coordination affects *account* and *options*:

(11)a What are [[the impacts [on the account]] and [the options]]?

(11)b What are the impacts on [[the account] and [the options]]?

Coordination of nouns headed by a preposition is then ambiguous, as the second conjunct may be analyzed as a complement of the preposition or of a precedent verbal head.

It is also noteworthy that not only heads of the same category can be coordinated, but rather constituents realizing the same function, as in (12), where an adjective and a prepositional phrase are both predicative complements:

(12) If you feel your *skin dry and with* a less healthy aspect, the solution is *Bath and Body Works.*

Any complement may be coordinated. Arguments, like subjects and objects, will always be coordinated, but adjuncts will be only if they express the same type of semantic content. The following chart shows the frequencies of appearance of the coordinate conjunction distributed by type of structure in a selection of 100 utterances of our corpus: The types found are: coordination of verbs[4] (64%), use of "and" as a linking word[5] (14%), coordination of prepositional phrases[6] (7%), of direct objects (6%), of subjects (4%), of bare nouns (4%) and finally, coordination of adjectives (1%). Another significantly frequent case of coordination found in our corpus concerns the subcategorized coordination that we find in nouns such as *difference*, as in (13):

(13) What is the difference between a day cream and a night cream?

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[4] These data account for the coordination of both sentences and verb phrases sharing the same subject.

[5] Rather than coordination, these data reflect the use of the conjunction as a linking word: *And when are you coming?"*

[6] These data include the cases where a single preposition heads two coordinated nouns.

3. Related work: analyses proposed for coordination of constituents

Representing coordination represents a major challenge for syntactic models, since its structure seems to be quite different from the rest of the constructions found in grammar. Concerning phrase structure grammars, coordination has been analyzed in the X-bar model (Johannessen, 1998) considering the conjunct the head of the phrase, whereas its conjuncts are analyzed as its specifier and complement. Borsley (2005) provides arguments against this analysis, considering the difficulty of feature sharing between head, specifier and complement. Abeillé (2006) proposes an analysis in HPSG which considers the conjunction a weak head. Weak heads, proposed initially for dealing with marking prepositions (Abeillé & al., 2004) are a kind of head which inherits the category of their complement and mark the phrase they head. Coordinated phrases are then analyzed as headless phrases containing two or more conjunct phrases.

Dependency Grammar treats subordination as a kind of governor-governee dependency (just as heads and their dependants), but coordination, lacking a head/dependant asymmetry, hardly fits into this dependency relationship. Tesnière (1959) already proposes a new kind of dependency to deal with coordination: a horizontal relationship between conjuncts called *jonction*. This innovation has been criticized for not respecting the formal properties of the dependency model (Jäarvinen 1998), and although some proposal has been made to analyze coordination without extending the formalism (Mel'cuk, 1988), most of the solutions to analyze coordination include some extension to the Dependency Grammar model.

Mel'cuk (1988) proposes that conjunctions head coordination structures, since word order is sometimes non-reversible and the right conjunct (with the conjunction) is always omissible. However, this proposition presents some problems: the conjunction node lacks any semantic content, and it may take verbal complements without any constraints on its selective properties.

On the other hand, Hudson (1990) follows Tesnière (1959)'s proposition for coordination by positing that coordinate structures do not form phrases but *word strings,* where conjuncts do not hold any dependency relationship. He adds specific constraints to explain the particular properties of coordination (all conjuncts must share the same dependencies, etc.) For analyzing the inner structure of coordination, he adds a type of phrase structure information by stating that conjunctions head a special kind of phrase (*a distributional phrase*) whose distribution is not determined by its head, but by its complement Hudson (2006: 171-172), which has a special relationship (named *proxy relationship*) with its head. Hudson (1990)'s proposition accounts for this interesting distributional property of conjunctions[7]. This mechanism captures the same property as Abeillé (2006)'s concept of *weak head* and represents it in a dependency grammar. Nevertheless, it includes constituency information (the *word string*), so it does not answer to the question whether coordination can be successfully represented in pure dependency grammars (that is, without constituency information).

Jäarvinen & Tapanainen (1998) propose a different analysis in *Functional Dependency grammar* (FDG): the conjunction and the second conjunct are dependent on the first conjunct, just as if the second conjunct were a modifier of the first one. However, the resulting graph is order-dependent and the conjunct is still a governing non-semantic node.

More recently, Lison (2007) extends DG by using *bubble trees* (a mechanism conceived by Kahane (1999) for dealing with extraction) to account for coordination. It consists on positing a second level of representation within the coordinate structure, where *bubbles* act as brackets to indicate constituency phrases and shared dependency. This hybrid approach allows *Extended DG* (XDG) to deal even with complex cases of coordination, such as *argument cluster coordination*, but it also makes use of constituency information.

In conclusion, it seems that in order to deal with coordination in DG it is necessary to extend the formalism, and these extensions to DG (Mel'cuk's Meaning-Text Theory, Hudson's Word Grammar, Jäarvinen & Tapanainen's Functional Dependency Grammar and Lison's Bubble Trees) constitute hybrid formalisms including both dependency and constituency information. Schneider (1988: 43)'s affirmation seems then justified:

> Debates like the one between Hudson and Dahl have shown that on the one hand any syntactical theory has to implement elements of constituency – at least for coordination –, but that, on the other hand, every constituent grammar also needs some kind of dependency relations – at least for verb valency.

Mel'cuk's Meaning-Text Theory has been extended by Kahane (2000) and implemented in Polarized Unification Grammar (PUG). It includes some new machinery, such as quasi-dependencies, a special relationship to account for shared dependencies (e.g. the subject in control dependencies) and bubbles. Unlike Lison's bubble system, Kahane's (2000) bubbles do not introduce phrase structure information, but just allow the merging of a lexical item with no semantic content with a fully lexical one. This tool analyses the same cases as Abeillé

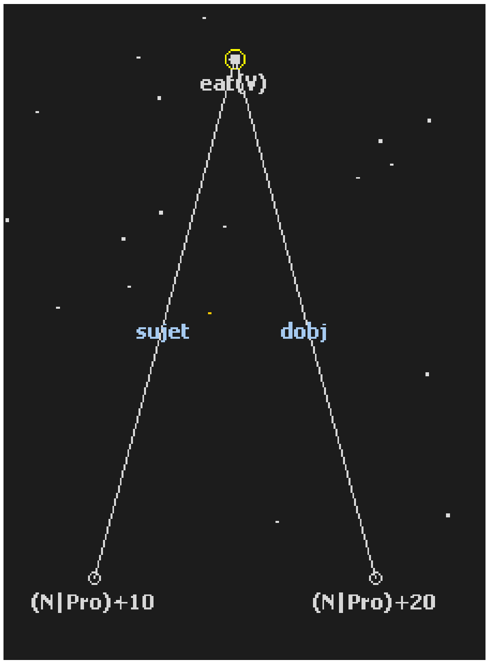
[7] Hudson (1990)'s *proxy relation* captures a property present in different phenomena: the property of being an optional item which introduces a phrase whose distribution is not determined by this item, but by its complement. Other than in coordination, this property is also found in *that* phrases: *that* heads the subordinate phrase, but it can be absent, and its distribution is determined by its verbal complement. : I know (that) you are tired.

(2006)'s *weak head* and Hudson (1990)'s *proxy relationship*, without using constituency information.

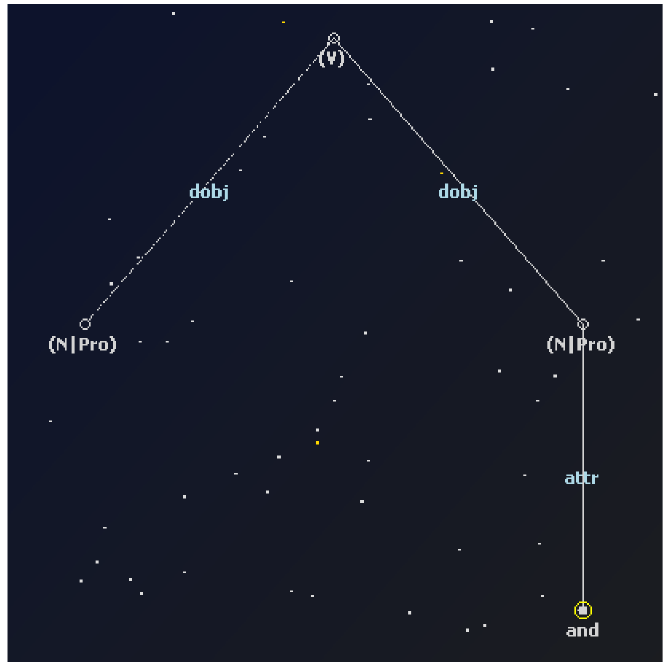
4. Formal analysis

The PUG implementation used by VirtuOz for human – machine dialogue analyses coordination in a similar way as the method proposed by Jäarvinen & Tapanainen (1998). This produces the undesired effects of lack of identity in the semantic analyses exposed in section 1 and illustrated in the introduction by (figure 1) and (figure 2). The methods for analyzing coordination presented below succeed in providing a single order-independent representation of utterances containing a coordination of constituents, without any information about constituency, against Schneider (1988).

One interesting feature introduced by Kahane (2006) that allows such an analysis is the possibility of unifying branches of different constructions. PUG analyses associate the constructions available in the grammar to each lexical item by unification of the nodes that will be saturated (if the lexical item is present in the utterance) or not. The construction for the verb *eat* (figure 3) illustrates this: the construction associated to it contains two non-saturated nodes that will be saturated by the presence of two nouns or pronouns. In the same way, branches can be unified in PUG if they are specified as such in a given structure, which is actually the case of one of the constructions for the coordinate conjunction *and* (figure 4):



(figure 3) Construction for transitive verb *eat*



(figure 4) Construction for and_1 (object coordination)

The idea underlying the construction is that the conjunct introduces a change in the realization of the dependency structure of the governor of the coordinated item. The second conjunct is analyzed as a dependant on the governor of the first conjunct, which realizes the same function. This analysis does not imply a change in the subcategorisation structure of the governor, but only a duplication of the function that the governee holds with it.

In (figure 4) the left branch is dotted to indicate that this is a unified branch, which is actually unified with the object branch of the argument structure of a verb. The second one is added as a special kind of adjunct, which agrees with the fact that it is optional. The conjunction is analyzed as a dependant of the second conjunct, with which it is amalgamated, just as a weak head or a proxy relationship[8]. This construction makes it possible to analyze utterances containing a coordination of objects, like (14)a-b, and its representation (image 5) meets both sentences:

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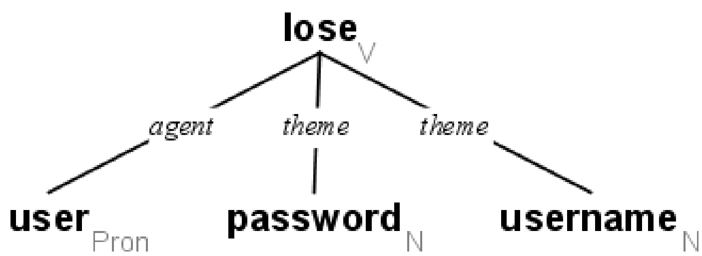
[8] It is interesting to note that amalgamation is not necessary to obtain this analysis, since the semantic contribution of the coordinating conjunction is null, and the result would be identical with or without lexical amalgamation. The concept of weak head is therefore not necessary for analyzing coordination of constituents in a DG enriched with unification of branches. Phrase structure grammars need tools like weak heads or proxy relationships because the conjunction is placed left to the lexical item and then analyzed as governing it.
The current analysis shows that the tool used to account for the phenomenon in phrase structure grammars is possible in DG.

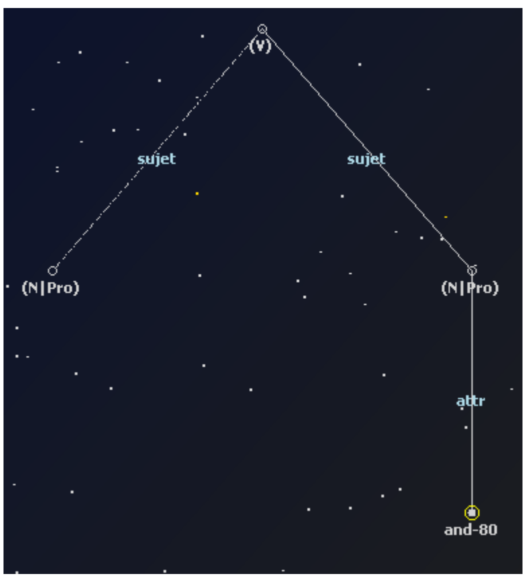


(figure 5) Graph for sentences (14)a and (14)b

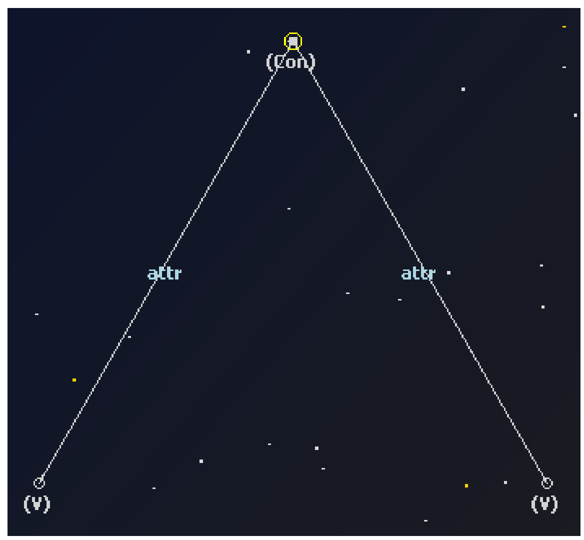
(14)a I've lost my username and password.

(14)b I've lost my password and username.

The construction for the coordination of subjects follows the same principles: the first branch indicates the subcategorized subject; whereas the second one represents the second conjunct, grouped with the conjunction (figure 6):

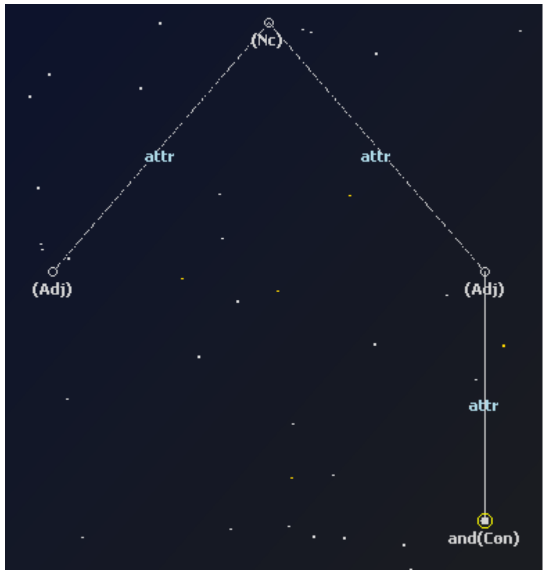


(figure 6) Construction *and*$_2$ (subject coordination)



(figure 7) Construction *and*$_3$ (sentence coordination)

A fourth construction for *and* accounts for the coordination of adjectives (figure 8), like in (15)a-b. Both branches are dotted here since both adjectives select the noun they modify, so both branches need to be unified with the one present in their structure.

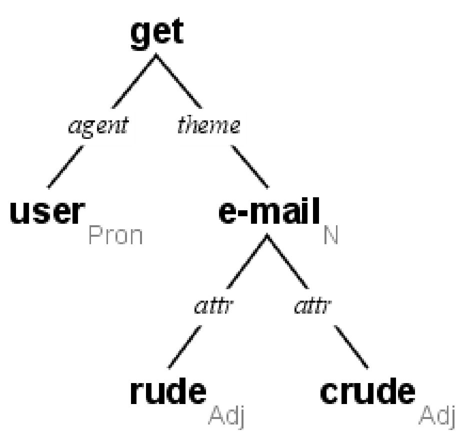


(figure 8) Construction for *and*$_4$ (adjective coordination)

(15)a I'm getting rude and crude emails.

(15)b I'm getting crude and rude emails.

The resulting analysis is also order-independent. The graph in (figure 9) represents both (15)a and (15)b:



(figure 9) Graph for sentences (15)a and (15)b

These four constructions for the conjunction *and* (which is exportable to other coordinating conjunctions or to its equivalent in other languages) can replace previous ones to render finer analyses. The kinds of coordination accounted for above are analyzed by these constructions. The cases where *and* can be analyzed as a linking word (see note 5) are analyzed by the construction for the coordination of objects, as an empty coordination. The same construction analyses the coordination of adverbs, which are both independent adjuncts of the verb. This is also the case of utterances such as (16), where several prepositional phrases are coordinated. The conjunction is then analyzed by the construction for coordination of subjects as an empty coordination. Finally, coordination of nouns is analyzed by the construction for the coordination of adjectives.

From the possible types of coordination presented above, two cases remain problematic: coordination of two prepositional objects (16), and coordination of nouns which are complements of a preposition (17). In the first case, the second conjunct will be analyzed as an adjunct, and in the second one, it will be analyzed as the object of the preceding verb. These are today the limits of the VirtuOz PUG implementation for coordination. Nevertheless, the proposed analysis significantly improves the performance of the grammar in its human – machine dialogue system, as can be seen in next section.

(16) I need to sign up for ID and for password.

(17) How do I know how much to charge for package and postage?

5. Computational integration

As demonstrated in the introduction, replacing the old constructions for the conjunction "and" by the proposed ones would have the undesired consequence of losing language recognition for utterances containing coordination. The consequences of such modifications have been measured and a regression report has been prepared, following the steps already mentioned: creation of a coverage corpus and a list of the sentences stocked in the virtual agents' databases which contain "and".

The coverage corpus is composed of a list of sentences that shows the diversity of possible coordination types. The comparison between the sentences analyzed by means of the old and the new constructions indicates that the four new constructions are more efficient: They analyze a greater number of utterances and the new analyses are order-independent. Afterwards, a list of the 230 sentences containing "and" was retrieved from the corpus and every sentence was analyzed with the old and the new constructions. Finally, the results were compared in order to measure the benefits of the new constructions.

The regression report includes the result of this comparison: distribution of each type of coordination, percentage of order-independent analyses, and average time of analysis.

These results are shown in (figure 10), which compares the percentage of order-independent analyses and average time of analysis (expressed here in milliseconds) of the different types of coordination found among these 230 utterances: (in sequential order) coordination of sentences, nominal modifiers, objects, subjects, adjectives, PPs, nouns subcategorizing for a coordination (difference between X and Y), and others.

graphs \ coordination types	V & V	N & N N	V N & N	N & N V	Adj & Adj	Prep N & N	N between X & Y	other	**TOTAL**
quantity	88	18	55	14	12	25	16	4	**230**
% order independent NEW	50	55,5	67,2	64,2	33	0	56,2	25	43,80%
% order independent OLD	14	11,1	0	0	8,3	0	7,1	0	5%
Time average NEW	3000	1647	2190	1340	2312	3628	3117	680	**1661**
Time average OLD	18275	20811	12048	8363	5314	25056	1437	5148	**5668**

(figure 10) Results of regression report

These data show that with order-independent analyses, language recognition increases by around 40% in average, and by 60 % in some cases. In the same way, time of analysis is shown to be reduced significantly.

6. Conclusions

The new analyses of coordination proposed here presuppose some formal extensions to DG: unification of branches and, optionally, fusion of a lexical and a grammatical word (called *bubbling* here). In exchange, it allows word-order independent DG / MTT representations, which are missing in precedent analyses. This theoretical innovation may be employed in industrial applications, such the VirtuOz application, where they would significantly reduce computing time and human workload.

The possibility of integrating constructions which allow such an improvement has been checked in a test database, and measured in terms of cost and benefit. On the one hand, the costs involve implementing 4 constructions for the coordinate conjunction and manually adapting the graphs of the 230 sentences that are currently stored with a different analysis. On the other hand, the benefits are a shorter time of analysis and a reduction of human workload, since new coordinate sentences will have to be stored in the databases just once, and not twice as before.

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