Error diagnosis for language learning systems*

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Abstract

A diagnostic component for natural language utterances has been devised which allows one to integrate (possibly inconsistent) evidence from a wide range of knowledge sources into a unique decision procedure. It is based on a procedure for the disambiguation of dependency structures using graded constraints. Different description levels like syntax, semantics, and others are treated by separate structural representations, which are disambiguated simultaneously. Due to the complete symmetry of the system architecture the approach allows to handle a wide variety of student errors successfully.

1. Introduction

If a language tutoring system is expected to stimulate the creative use of language in communicatively relevant settings *and* to provide the student with an adequate level of feedback, it has to solve two tasks at the same time:

1. Determination of a structural interpretation of the student's utterance even in the presence of considerable local ambiguity and the possible existence of unexpected or unacceptable constructions (Robust parsing)
2. Identification of ungrammatical constructions and inappropriate communicative behavior in terms of explanation possibilities and strategies for remedy (Fault diagnosis)

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Although there is more to a good language learning system than just parsing and diagnosis, these two capabilities are needed as core functionality if such systems are expected to depart from a few predefined examples towards a more flexible interaction which at least partly resembles the goal-oriented nature of human communication. Based on this core functionality individualized strategies for tutoring and remedy can then be designed and validated in a second step. Focussing on error diagnosis need not imply that errors are going to be emphasized in the learning process. Precise diagnostic results form an indispensable foundation for deliberately choosing an appropriate system response even if ignoring the error finally turns out to be the optimal decision.

Unfortunately, robust parsing and fault diagnosis are almost incompatible tasks. On the one hand, parsing can be performed efficiently only if reliable hypotheses about the particular problems in an erroneous utterance are available (e. g. 'If the case of this noun was nominative instead of dative, it could be the subject of the sentence'). Therefore, consistency checks for such well-formedness conditions, which are the most important means to restrict the hypothesis space for structural interpretations, are no longer available. On the other hand, diagnosis requires rather strong assumptions about the underlying structure of the utterance (e. g. 'If this constituent is meant to be the subject of the sentence, it is of wrong case'). Thus, preliminary parsing hypotheses are always needed prior to the diagnosis, and at the same time diagnostic results are prerequisites of an effective parsing procedure.

Moreover, while robust parsing requires to at least partially ignore certain regularities of the language system (otherwise no interpretation can be found for a deviant utterance), diagnosis needs to check whether the same well-formedness conditions hold (otherwise not a single error can be detected).

To reconcile these contradictory requirements the integration of additional information from the situational context of the exercise will become necessary. This not only enables the structural analysis to access further sources of constraining information but comes with the particular advantage that the communicative contribution of an utterance can be judged upon as well. Syntactic well-formedness is no longer treated in isolation but considered one among a variety of factors contributing to the successful interpretation of natural language.

To mimic partial aspects of such an integrative approach a prototype system for robust parsing and error diagnosis has been set up combining

- a multi-level representation which allows to bring together syntactic, semantic, pragmatic, and domain-specific knowledge in a uniform way,
- the use of graded, hence defeasible, constraints on all representational levels, and
- a common arbitration mechanism which allows to weigh evidence from very different sources against one another.

The system is based on a procedure for structural disambiguation, which eliminates elementary structural descriptions from an initially complete, but highly underspecified representation of all structural interpretations for a given utterance. Thus, it especially facilitates the comparison of alternative interpretations and the arbitration of possibly contradictory evidence. After first discussing basic requirements and existing approaches to robust behavior in natural language processing systems, Section 3 puts forward an alternative proposal and gives a short introduction to the underlying idea of candidate elimination. The proposed approach allows one to find structural interpretations even in the presence of severe constraint violations, which in turn can easily be interpreted as diagnostic descriptions. To further enhance the robustness properties Section 5 introduces a multi-level representation and, finally, its application in different educational settings is discussed.

2. Robust Parsing

Robust behavior for natural language parsing systems is usually attempted by means of over-generating rule systems, which contain *error rules* for extra-grammatical phenomena. For language learning purposes this implies to anticipate and explicitly specify every erroneous construction which could possibly be produced by a student (Yazdani 86; Schneider & McCoy 98). An alternative approach uses *constraint retraction* techniques where certain well-formedness conditions are temporarily ignored if otherwise no consistent structural description can be generated (Uszkoreit 91). Weaker instances of grammar rules are derived from the normal ones whenever this seems necessary. Applications to the area of foreign language learning usually require a combination of both techniques. Schwind (95), for instance, uses a constraint retraction approach for the class of agreement errors and error rules for structural faults (e. g. missing constituents, inappropriate linear orderings etc.). While error rules lend themselves easily to the creation of small-scale demonstration systems, it seems, however, infeasible to exhaustively anticipate every potential error configuration and to describe it by means of corresponding error rules. Constraint retraction techniques, on the other hand, require a rather strong structural backbone to rely upon. Therefore, their application is usually restricted to selected types of regularities and severely limited exercises (Menzel 88; Menzel 90; Menzel 92).

Both error rules and constraint retractions provide a good starting point for the derivation of error diagnoses. As long as singleton errors are considered, simple error explanation schemes can be defined and used to produce the desired feedback for the student. Unfortunately, both techniques lead to tremendous efficiency problems since they neutralize valuable information, which even in the error free case is urgently needed to constrain the search space. This problem becomes a particularly serious one, because neither approach uses graded ratings for (partial) structural hypotheses and, therefore, does without an important means to guide the search for an appropriate solution. Particularly, the application of empirically obtained gradings in probabilistic grammars has turned out to be a major factor for introducing a considerably higher degree of robustness in the parsing of natural language (Briscoe 94). However, probabilistic grammars have to be trained on huge corpora of natural language examples, taken e. g. from running newspaper texts. If a grammar for diagnostic purposes is required it will need to be trained on similar collections of typical learner utterances. This approach does not seem particularly promising since it can hardly be imagined how a corpus could be collected, which is statistically representative not only with respect to relevant language structures but moreover to possible error situations *and* exercise types. Notice that one and the same utterance can be acceptable in one context but quite inappropriate in another. Therefore, the probabilistic approach would require corpora which are properly annotated according to the different error categories and exercise contexts, because only then it might become possible to induce the relevant information about the distinction between the acceptable and the unacceptable case from the given data.

Like most contemporary approaches to robust parsing probabilistic grammars suffer from a biased focus on the isolated treatment of syntactic phenomena. This syntax-oriented approach not only causes severe difficulties with respect to local ambiguity and efficiency, but also it puts tremendous limitations on the quality of diagnostic results since it reduces diagnosis to a context insensitive similarity comparison. For example, a purely syntax-based diagnosis will certainly find two equally likely explanations for the number disagreement in the example (1) where the noun can be corrected to singular, or alternatively the verb can be changed to plural.

(1) **The children laughs.*

Given a suitable context (e. g. where only one child is under consideration) this diagnostic uncertainty immediately disappears. In certain cases contextual information might even put a much stronger perspective on an utterance which eventually can override syntactic evidence. In such cases a convincing diagnosis can only be obtained if the diagnostic component takes into consideration as much contextual information as possible. Such a representation of context conditions should include knowledge about the domain of discourse, about the discourse situation (who is speaking to whom, where, and when) as well as about previous discourse contributions.

This contextual embedding then provides an anchor point for the diagnosis, and error explanations can be found which are well motivated in the given situation. Not surprisingly, a quite similar strategy can also be observed with human teachers, who never consider an erroneous utterance in isolation, but try to collect evidence from very different sources to infer the most likely intention behind the student’s contribution. These assumptions about the underlying intention are not only used to find a plausible diagnosis but, furthermore, serve as a reference for possible repair proposals.

On the other hand, it should be noticed that contextual information never provides an absolute point of reference. In any case it is based on nothing but *assumptions* on likely student behavior (e. g. she will answer a given question properly) and nobody is able to prevent a student from producing strange responses. Under these circumstances any assumption about plausible behavior is doomed to fail and might become subject of diagnostic efforts itself.

To avoid a system break down under such circumstances every piece of model information has to be defeasible, and partial representations for the different levels of language have to be loosely coupled. The robust behavior and diagnostic abilities of the system are based on the assumption that combined deviations on different levels will be encountered only in rather exceptional cases. Under usual conditions a bi-directional information flow among representational levels will facilitate mutual support which allows to overcome, for instance, syntactic difficulties by means of semantic or domain-specific knowledge and vice versa.

3. Eliminative Parsing

In contrast to the traditional notion of parsing as a constructive process, which successively builds more complex structures out of elementary building blocks, an eliminative approach starts with a totally ambiguous representation containing all possible dependency structures of an utterance at the same time. The parser then tries to discard local interpretations from this structure by applying unary or binary constraints on dependency relations until - hopefully - a single global reading survives. Thus, parsing becomes a procedure of structural disambiguation, which is based on constraint satisfaction techniques. Although the number of possible readings grows exponentially, only a relatively small number of edges is actually maintained during the disambiguation process because most of them can be eliminated quite early. Figure 1 shows the initial state of the process for a syntactic representation of the German sentence

(2) *Der Mann besichtigt den Marktplatz.*
The man visits the marketplace.

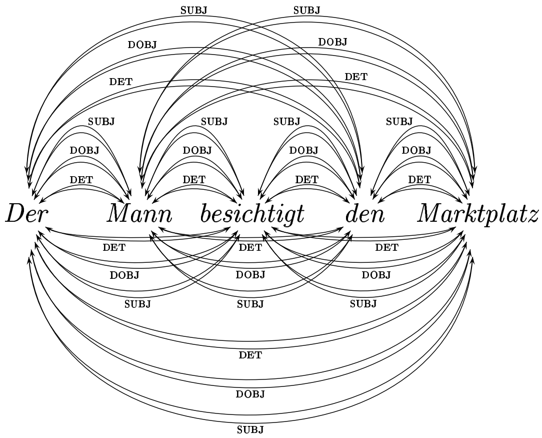

Figure 1: The initial state of a parsing problem: Each word form modifies each other with every possible label.

The representation is simplified as only three different kinds of syntactic dependency relations are taken into account:

- **DET:** the modification of a proper noun by a determiner
- **SUBJ:** the modification of a finite verb by the head of a noun phrase as the subject
- **DOBJ:** the modification of a finite verb by the head of a noun phrase as the direct object

The application of three unary constraints, namely

- A determiner modifies a noun to its right with the label DET.
- A noun can modify a finite verb either as the subject or the direct object.
- A finite verb modifies nothing.

already removes a vast amount of subordination possibilities.[1] The resulting hypothesis space is given in Figure 2.

[1] All the mentioned constraints are crude generalizations, which have to be refined considerably to properly describe the general case.

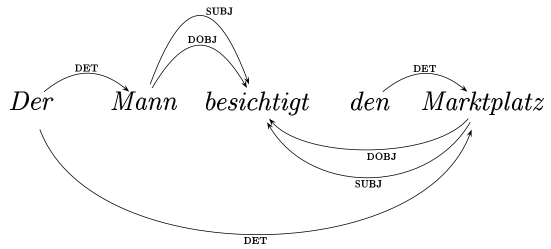

Figure 2: The space of possible dependency relations after the application of unary constraints.

Unfortunately, it still contains a couple of different dependency structures and a complete disambiguation can only be achieved by means of two additional binary constraints

- A word form can not be modified twice with the same label.
- Nominative case is required for the complete subject phrase.

Now, only a single dependency tree remains, as depicted in Figure 3.

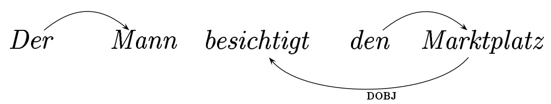

Figure 3: A uniquely disambiguated dependency structure.

Eliminative parsing has first been introduced by Maruyama (90) to be used in an interactive machine translation system. As one of its main advantages it offers the possibility to directly compare competing hypotheses and therefore can be extended easily to the treatment of *graded constraints* (Menzel 98; Heinecke et al. 98), where gradings determine how serious one considers a constraint violation, thus yielding constraints of different strength: Hard ones must be satisfied in any case while most others penalize undesired dependency relations to a different degree. The parser tries to select a structural interpretation which violates only as few and as weak constraints as possible. This selection is highly facilitated due to the simultaneous availability of alternative readings (c. f. Figure 1 and 2) and different decision procedures can be applied to obtain the desired interpretation (Menzel & Schröder 98b).

Usually graded constraints are used to model preferences, defaults, and uncertainty. For example, even a seemingly symmetrical case like the erroneous sentence 3 can be disambiguated to a preferred reading by means of a simple precedence heuristics, which in the unmarked case puts the subject in front of the direct object.

(3) **Der Mann besichtigt der Marktplatz.*

The man$_{nom}$ visits the marketplace$_{nom}$

(4) **Der Mann besichtigt die Marktplatz.*

The man visits the$_{acc,fem}$ marketplace$_{acc,masc.}$

In a similar manner, constraint violations may become acceptable if the corresponding constraint receives an appropriate grading as in sentence 4. Thus, by weakening an increasing amount of constraints, which are normally considered hard ones, a certain degree of robustness against constraint violations is introduced into the parsing procedure (Menzel & Schröder 98a). It can be used to derive structural hypotheses about ungrammatical utterances, which later are used to provide a structural backbone for explanatory purposes.

4. Diagnosis

Typically, the dependency structure obtained for an ungrammatical utterance will violate one or even several of the constraints in the grammar. Fortunately, such inconsistencies can be easily identified by the constraint satisfaction procedure and converted into error explanations in a straightforward manner. This close correspondence between constraint violations and error explanations has already been noted by Ohlsson (94) who proposed a constraint-based approach to the diagnosis of student errors but restricted its application to completely unambiguous problems. Our experience has shown that the idea can also be transferred to the highly ambiguous environment of error diagnosis in natural language utterances. If the corresponding constraints receive an appropriate grading, a good deal of agreement violations, linear ordering problems, missing obligatory constituents, violated government requirements, and ignored sortal restrictions can be diagnosed directly (Menzel & Schröder 98a). In certain cases of structural faults the procedure will only be able to derive partial structural descriptions for the input utterance. Even then a

subsequent integration component can try to derive error explanations from the fragmentary parsing results (Menzel & Schröder 98c).
Obviously, the application of graded constraints serves the two above-mentioned purposes at the same time: robust parsing *and* fault diagnosis for a wide range of (possibly ill-formed) utterances. The same mechanism of arbitration between conflicting evidence allows us to tolerate *and* identify constraint violations. Being designed to determine the least corrupted interpretation among a vast variety of competing structural hypotheses, the procedure is able to perform a structural analysis of the utterance producing diagnostic results as a byproduct. Note that due to the use of graded constraints the threshold which triggers the generation of an error explanation can be dynamically adjusted to the student's current level of proficiency: While in a highly distorted utterance only the most severe constraint violations are flagged, on a more advanced level even more subtle preferences can be explained.

5. Multi-Level Parsing

Unfortunately, the gradual weakening of constraints introduces the same kind of problem any constraint retraction mechanism suffers from: The search space increases considerably and severe efficiency problems are incurred. This problem can only partially be compensated for by the introduction of preferential knowledge. To provide an appropriate countermeasure a possibility to consider additional knowledge from independent sources has been devised which is based on a multi-level representation. The system uses different description levels like syntax, semantics, and domain specific relations which are treated by separate structural representations (c. f. Figure 4a).

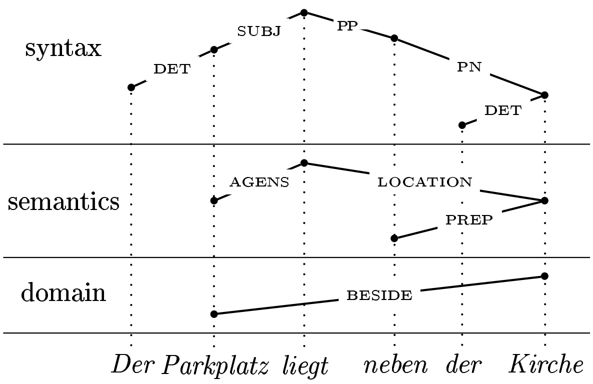

Figure 4a:
A multi-level representation for the sentence
'The car-park lies beside the church.'

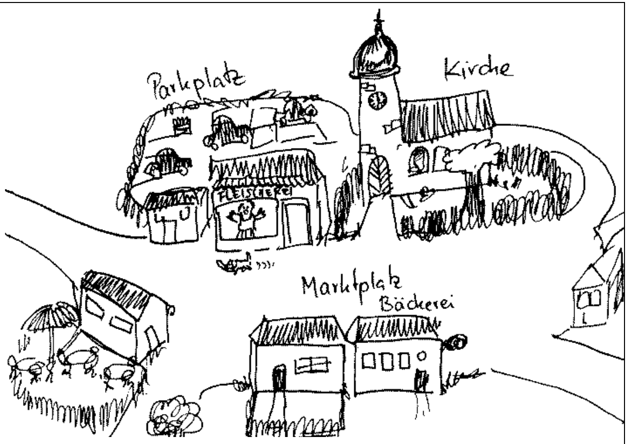

Figure 4b:
Pictorial representation
of the exercise context

Structures on the various description levels are mapped onto each other by means of graded constraints and are disambiguated simultaneously.[2] Therefore, evidence from one level might help to find appropriate structures on the other ones. In particular, expectations about the propositional content can put a strong preference on certain semantic interpretations whenever the appropriate knowledge can be derived from the given context of the exercise. Thus, given a proper instantiation even a syntactically well-formed sentence like 5 which, if considered in isolation, seems quite counterintuitive, can be interpreted in a sensible - i. e. context related - way and corrected appropriately.

(5) ?*Der Marktplatz besichtigt den Mann.*
The marketplace visits the man.

The information which is necessary to bias the semantic level in a suitable way might for example be derived from a pictorial representation (c. f. Figure 4b) which is given to the student as a common background to be talked about. Note that this bias towards a particular interpretation does not create a fatal dependency on one particular point of view. Thanks to the graded nature of mapping constraints, the cross-level coupling is a loose one and might be subject to constraint violations as well. The flow of information is

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[2] Separate representation levels are also used to model syntactic subcategorization properties, e. g. the intransitive verb 'visit' requires a subject and a direct object.

completely symmetrical so that e. g. syntactic evidence can support semantic interpretation but also vice versa. Conflicting information is arbitrated by taking into account the accumulated constraint weights. If strong enough, both syntactic and semantic cues are able to override an inconsistency on the corresponding complementary level.

For evaluation purposes a prototypical diagnosis component for German as a foreign language has been developed. Although the prototype is limited yet, it has shown to be sophisticated enough to be immediately applied within a teaching unit. So far the grammar contains nearly 220 constraints and covers the following syntactic phenomena: active (future, present, perfect, past, and past perfect) and passive (present and past) voice of the verb, verbal and nominal genitive attributes, nominal groups including articles, adjectives, and nouns (declination classes, definiteness, and adverbial adjective modifiers), prepositional phrases, and simple subordinated clauses. Modal verbs, negations, relative clauses, and coordinations have not been dealt with yet. In order to study the robustness properties of this grammar the example sentence (2) has been systematically distorted by introducing different kinds of syntactic errors, and a global error measure has been defined to describe the degree of disorder for the resulting variations of the example utterance:

- **Case agreement:** The case of the subject as well as the object has been varied to take nominative, genitive, and accusative case respectively. While a shift from nominative or accusative to genitive counts as a single error, mixing up nominative and accusative counts as a double fault, because it is more difficult then to get the structural interpretation right.
- **Number agreement:** Analogous to the case parameter the subject and the object have been assigned singular and plural word forms. Note that, although there is no number agreement between finite verb and object in German, the chance of interchanging subject and object increases if the desired object agrees with the verb. Therefore, the analysis becomes increasingly more difficult when one abolishes the agreement of the subject and establishes it for the object.
- **Word order:** While German has a relatively free word order, there is nevertheless a slight preference of placing the subject in front of the object. It should be noted that the

marked word order does not count as an error, but a preferred word order nevertheless helps to find the correct analysis.

While the correct sentence (2) has an error degree of zero, sentences (3), (4), and (5), for instance, have an error degree of two, one, and five, respectively. The 72 syntactic variations are analyzed in nine different contexts where the sortal restrictions of the verb as well as the domain knowledge either support, do not influence, or contradict the desired solution. Therefore, in addition to the syntactic parameters two more dimensions are introduced:

- **Sortal restrictions:** This criterion determines whether the semantic classes of the desired arguments match the sortal restrictions of the verb. A neutral value means that no sortal restrictions are checked, e. g. due to missing information.
- **Domain knowledge:** This parameter determines whether the utterance is considered true or false in the domain. Given that the context of the exercise supports the desired interpretation, all other readings get penalized, while a contradiction with the context leads to a degradation of the desired interpretation.

Example sentence (6), for instance, violates the sortal restrictions of the verb and sentence (7) may be considered false in the domain under consideration.

(6) *Die Kirche besichtigt den Marktplatz.*
The church visits the marketplace.

(7) *Der Mann besichtigt die Kirche.*
The man visits the church.

This results in 648 different sentences which are used for the evaluation of the diagnostic quality. Figure 5 shows the percentage of correctly analyzed ones depending on the syntactic error measure for a supporting, neutral, and violating context respectively. Using the available information on a complementary level as an anchor point, even utterances with a remarkable number of errors can be analyzed correctly. The analysis fails to find the desired interpretation only in cases of highly complex distortions. While nearly half of the results for sentences with an error measure of three were wrong when only the syntactic level was represented, almost all utterances with an error measure up to five are interpreted correctly when enough semantic and domain-specific support is available. Of course, contradicting semantic and/or domain-specific expectations lead to a decrease in syntactic robustness. This was to be expected because of the symmetry of representation levels and constraints. The use of different knowledge levels leads to synergy, since none of the representation levels alone could achieve a similar degree of robustness.

It should be noted that, although we have stressed the robustness against syntactic deviations to enable the comparison of the multi-level representation with the syntax-only case, the robust behavior is symmetrical with respect to the different levels. Thus, positive information on the syntactic level also helps to find a (possibly unexpected) semantic interpretation, a mode of operation, which resembles the more traditional sequential architectures where semantic processing is based on the output of the syntactic component.

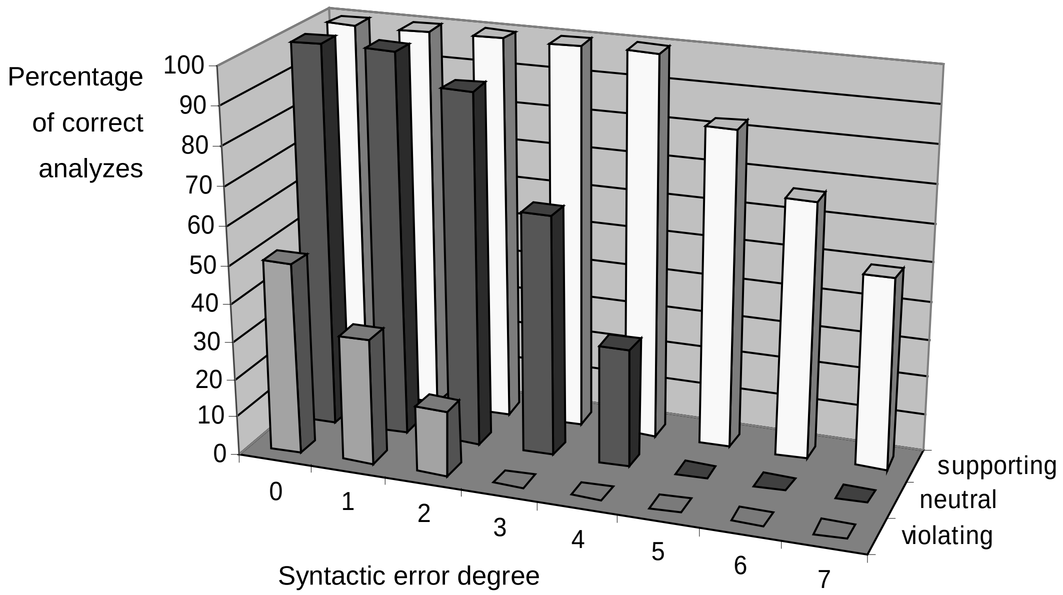

Figure 5: Percentage of correct analyzes depending on the number of syntactic errors and, additionally, parameterized by the kind of semantic and domain-related support: The better the semantic and domain-specific support, the more errors can be compensated for.

6. Learning Environments

Due to the symmetry of the system architecture, the resulting error sensitive parsing component seems apt to considerably further the development of truly interactive language learning environments and opens up interesting possibilities for being applied in a wide variety of educational settings. As an alternative to the use of propositionally represented pictorial information the semantic level can also be instantiated with the propositional content of a short introductory text, which is presented to the student. If later the student is asked to answer corresponding questions, basically the same procedure can be used

- to diagnose syntactic errors based on the available semantic support, and
- to identify comprehension problems by detecting possible contradictions with respect to the semantic bias which even can be traced back to a previous misunderstanding when reading the text.

Imagine that the story again is about a man visiting the marketplace and the student inputs the syntactically perfect but propositionally deviant utterance in example (7). The diagnosed mismatch between the background knowledge and the parsing result might trigger a request to check again whether it really was the church that the man visited.
Although the architecture usually makes use of domain specific knowledge to support the diagnosis of erroneous utterances, it includes this knowledge in a way, which does not require the propositions to always be true. Semantic and domain specific constraints can be violated in the same way as syntactic ones. Hence, a possibly fatal dependency on a particular source of information is avoided, a characteristics which is novel among the existing approaches to robust parsing.
If embedded into an interactive environment which allows to manipulate a virtual micro-world, the diagnostic component provides all the prerequisites for engaging the student in a variety of pedagogically interesting interactions. Hamburger (95) distinguishes eight interaction types among which the following five are most relevant for the application of an error sensitive component for language analysis:

- Quizmaster: The system asks a question with respect to the background knowledge and the student gives an answer.

- Movecaster: The system generates an (animated) graphics and the student tells, what she sees.

The system checks the student's utterance for grammatical and pragmatical acceptability, where the graphically presented information serves as support for the treatment of erroneous constructions. In both cases the initiative rests completely with the system, a situation which allows to carefully control the degree of freedom for possible student responses. Other interaction types, which encourage the student to also take the initiative are:

- Oracle: The student asks a question and the system gives an answer.
- Servant: The student gives a verbal command and the system changes the micro-world accordingly.
- Interpreter: The student tells a simple story and the system generates a corresponding animation.

Moreover, the interactive manipulation of a graphical representation can even be used as an alternative communication channel, whenever the verbal communication breaks down due to insufficient language capabilities of the student. By directly manipulating the objects of the graphical representation, the student can try to visualize her intended communicative goal. Thus, she provides the system with additional information to be used in guiding the diagnosis towards a plausible interpretation. To support a uniquely visualization of simple verbal utterances in such communicative situations Mealing and Yazdani (Mealing & Yazdani 93; Yazdani & Mealing 93) suggest a compositional and partly animated language based entirely on pictograms.

7. Conclusions

Based on the eliminative parsing approach we have set up an experimental system for language learning. The system accepts typed single-sentence descriptions of static relations between local entities in a simple town scenery (c. f. Figure 4a & b). While offering the student a rather comfortable degree of freedom to choose appropriate verbal expressions according to her individual preferences, the system allows one to diagnose a wide variety of student errors. In the usual case, syntactic irregularities will be identified relying on evidence from semantics or domain knowledge. Additionally, violations of contextual conditions (resulting e. g. from problems of reading comprehension) can be detected, if only the syntactic evidence from the student's utterance is reliable enough. Thus the analysis uses available evidence from complementary levels to anchor its diagnostic decisions and, additionally, is able to dynamically switch the anchor point according to the diagnostic situation, since both types of errors are treated with the same computational mechanism. Simple written feedback is generated from the diagnostic results by an interpretation component to explain possible errors to the student.

The mapping between the errors found and the type of feedback is independent of the diagnosis component so that more complex and elaborated components can be plugged into the system when they become available. Here a wide range of alternative feedback types can be imagined:

- providing an analogous construction,
- entering a clarification dialogue, or
- invoking a specialized follow-up exercise

Compared to anticipation-based techniques for error-sensitive parsing, the presented approach is based completely on a model for error-free language structures. Therefore, the obvious difficulties with providing a rich enough set of mal-rules can be avoided. Furthermore, the natural redundancy contained in a multi-level representation allows one to overcome the efficiency problems which both mal-rules and constraint retraction techniques introduce. Instead of expecting the system to pull itself up by its own bootstraps an external point of reference is provided which biases the analysis towards a preferred (context-related) reading without, however, creating a unidirectional dependency.

The diagnostic results obtained so far confirmed a rather high degree of robustness and diagnostic quality. However, the system still suffers from a number of serious simplifying assumptions, which have been made to keep the complexity of constraint modeling manageable during the initial development phase

- Only a completely static world is modeled.
- An almost trivial model of reference resolution is used, i. e., nouns are assumed to uniquely denote referential objects in the micro-world.
- There is only an extrinsic perspective on the objects of the micro-world.

- Only relatively simple, narrative utterances are considered.

Some of these shortcomings can be attributed to the impoverished world model and can be overcome by integrating a more elaborate knowledge representation and inference subsystem with the diagnosis component. It remains to be shown that the considerable advantages of the integrated approach to robust parsing and fault diagnosis can be retained even if these limitations are removed successively.

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