ABSTRACT

In this paper, we argue that type inferencing incorrectly implements appropriateness specifications for typed feature structures, promote a combination of type resolution and unfilling as a correct and efficient alternative, and consider the expressive limits of this alternative approach. Throughout, we use feature occurrence restrictions as illustration and linguistic motivation.

1 INTRODUCTION

Unification formalisms may be either untyped (DCGs, PATR-II, LFG) or typed (HPSG). A major reason for adding types to a formalism is to express restrictions on feature occurrences as in GPSG [6] in order to rule out nonexistent types of objects. For example, there are no verbs which have the feature +N. The simplest way to express such restrictions is by means of an appropriateness partial function $\text{Approp}:\text{Type} \times \text{Feat} \rightarrow \text{Type}$. With such an appropriateness specification many such restrictions may be expressed, though no restrictions involving reentrancies may be expressed.

In this paper, we will first in §2 survey the range of type constraints that may be expressed with just a type hierarchy and an appropriateness specification. Then in §3, we discuss how such type constraints may be maintained under unification as exemplified in the natural language parsing/generation system Troll [8]. Unlike previous systems such as ALE, Troll does not employ any type inferencing. Instead, a limited amount of named disjunction (\{5\}, \{7\}) is introduced to record type resolution possibilities. The amount of disjunction is also kept small by the technique of unfilling described in [10]. This strategy actually maintains appropriateness conditions in some cases in which a type inferencing strategy would fail. Finally, in §4, we discuss the possibilities for generalizing this approach to handle a broader range of constraints, including constraints involving reentrancies.

2 APPROPRIATENESS FORMALISMS

As discussed in Gerdemann & King [9], one can view appropriateness conditions as defining GPSG style feature occurrence restrictions (FCRs). In [9], we divided FCRs into conjunctive and disjunctive classes. A conjunctive FCR is a constraint of the following form:

- if an object is of a certain kind
- then it deserves certain features
- with values of certain kinds

An FCR stating that a verb must have v and n features with values + and — respectively is an example of a conjunctive FCR. A disjunctive FCR is of the form:

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-1 The Troll System was implemented in Quintus Prolog by Dale Gerdemann and Thilo Götz.
if an object is of a certain kind
then it deserves certain features
with values of certain kinds,
or it deserves certain (perhaps
other) features with values of
certain (perhaps other) kinds,
or ...
or it deserves certain (perhaps
other) features with values of
certain (perhaps other) kinds.

For example, the following FCR stating
that inverted verbs must be auxiliaries is
disjunctive: a verb must have the features
INV and AUX with values + and +, − and+
, or − and − respectively.

Both of these forms of FCRs may be expressed
in a formalism employing finite
partial order \( \langle \text{Type, } \subseteq \rangle \) of types under
subsumption, a finite set \( \text{Feat} \) of features,
and an appropriateness partial function
\( \text{Approp}: \text{Type} \times \text{Feat} \rightarrow \text{Type} \). Intuitively,
the types formalize the notion of kinds of
object, \( t \subseteq t' \) iff each object of type \( t' \)
is also of type \( t \), and \( \text{Approp}(t, f) = t' \) iff each
object of type \( t \) deserves feature \( f \) with
a value of type \( t' \). We call such a formalism
an appropriateness formalism. Carpenter’s
ALE and Gerdemann and Götz’s Troll
are examples of implementations of
appropriateness formalisms.

How an appropriateness formalism encodes
a conjunctive FCR is obvious, but
how it encodes a disjunctive FCR is less
so. An example illustrates best how it is
done. Suppose that FCR \( \rho \) states that
objects of type \( t \) deserve features \( f \) and \( g \),
both with boolean values and furthermore
that the values of \( f \) and \( g \) must agree. \( \rho \)
is the disjunctive FCR

\[
\begin{align*}
\text{if an object is of type } t \\
\text{then it deserves } f \text{ with value } + \\
\text{and } g \text{ with value } +,
\text{or it deserves } f \text{ with value } - \\
\text{and } g \text{ with value } -
\end{align*}
\]

To encode \( \rho \), first introduce subtypes, \( t' \)
and \( t'' \) of \( t (t \subseteq t', t'') \), one subtype for
each disjunct in the consequent of \( \rho \). Then
encode the feature/value conditions in
the first disjunct by putting \( \text{Approp}(t', f) = + \)
and \( \text{Approp}(t', g) = + \), and encode the fea-
ture/value conditions in the second dis-
junct by putting \( \text{Approp}(t'', f) = - \) and
\( \text{Approp}(t'', g) = - \).

This approach makes two important
closed-world type assumptions about the
types that subsume no other types (hence-
forth species). First, the partition condi-
tion states that for each type \( t \), if an
object is of type \( t \) then the object is of ex-
actly one species subsumed by \( t \). Second,
the all-or-nothing condition states that for
each species \( s \) and feature \( f \), either every
or no object of species \( s \) deserves feature
\( f \). An appropriateness formalism such as
\( \text{ALE} \) ([2], [3]) that does not meet both con-
ditions may not properly encode a disjunc-
tive FCR. For example, consider disjunc-
tive FCR \( \rho \). An appropriateness formal-
ism may not properly encode that \( t' \) and \( t'' \)
represent all and only the disjuncts in the
consequent of \( \rho \) without the partition con-
dition. An appropriateness formalism may
not properly encode the feature/value condi-
tions demanded by each disjunct in the
consequent of \( \rho \) without the all-or-nothing
condition.

As indicated above, ALE is an example of a
formalism that does not meet both of
these closed world assumptions. In ALE a
feature structure is well-typed iff for each
arc in the feature structure, if the source
node is labelled with type \( t \), the target
node is labelled with type \( t' \) and the arc is
labelled with feature \( f \) then \( \text{Approp}(t, f) \subseteq t' \).
Furthermore, a feature structure is
well-typable iff the feature structure sub-

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2This example FCR is, for expository purposes,
quite simple. The problem of expressing FCR’s,
however, is a real linguistic problem. As noted by
Copestake et al. [4], it was impossible to express
even the simplest forms of FCRs in their extended
version of ALE.

The basic principle of expressing FCRs also ex-
tends to FCRs involving longer paths. For example,
to ensure that for the type \( t \), the path \( (fg) \)
takes a value subsumed by \( s \), one must first intro-
duce the chain \( \text{Approp}(t, f) = u, \text{Approp}(u, g) = s \).
Such intermediate types could be introduced as
part of a compilation stage.

3Note that these closed world assumptions are
explicitly made in Pollard & Sag (1994) [14].
also shown that a feature structure meets all encoded FCRs if the feature structure is satisfiable. The Troll system, which is structure such that encoding of \( R \) develops a notion of a satisfiable feature structure. Related a semantics of feature structures and part of type inferencing fails? Consider again the type resolution. Based on this idea, effectively implements type inferencing.

By contrast, the Troll system described in this paper has an effective algorithm for deciding well-formedness, which is based on the idea of efficiently representing disjunctive possibilities within the feature structure. Call a well-typed feature structure in which all nodes are labelled with species a resolved feature structure and call a set of resolved feature structures that have the same underlying graph (that is, they differ only in their node labellings) a disjunctive resolved feature structure. We write \( FS \), \( RFS \) and \( DRFS \) for the collections of feature structures, resolved feature structures and disjunctive resolved feature structures respectively. Say that \( F' \in RFS \) is a resolvent of \( F \in FS \) if \( F \) and \( F' \) have the same underlying graph and \( F \) subsumes \( F' \). Let type resolution be the total function \( R: FS \rightarrow DRFS \) such that \( R(F) \) is the set of all resolvants of \( F \).

Guided by the partition and all-or-nothing conditions, King [12] has formulated a semantics of feature structures and developed a notion of a satisfiable feature structure such that \( F \in FS \) is satisfiable iff \( R(F) \neq 0 \). Gerdemann & King [9] have also shown that a feature structure meets all encoded FCRs if the feature structure is satisfiable. The Troll system, which is based on this idea, effectively implements type resolution.

Why does type resolution succeed where type inferencing fails? Consider again the encoding of \( \rho \) and the feature structure \( \varphi \). Loosely speaking, the appropriateness specifications for type \( t \) encode the part of \( \rho \) that states that an object of type \( t \) deserves features \( f \) and \( g \), both with boolean values. However, the appropriateness specifications for the speculative subtypes \( t' \) and \( t'' \) of type \( t \) encode the part of \( \rho \) that states that these values must agree. Well-typability only considers species if forced to. In the case of \( \varphi \), well-typability can be established by considering type \( t \) alone, without the partition condition forcing one to find a well-typed species subsumed by \( t \). Consequently, well-typability overlooks the part of \( \rho \) exclusively encoded by the appropriateness specifications for \( t' \) and \( t'' \). Type resolution, on the other hand, always considers species. Thus, type resolving \( \varphi \) cannot overlook the part of \( \rho \) exclusively encoded by the appropriateness specifications for \( t' \) and \( t'' \).

3 MAINTAINING APPROPRIATENESS CONDITIONS

How may these \( DRFS \) be used in an implementation? A very important property of the class of \( DRFS \) is that they are closed under unification, i.e., if \( F \) and \( F' \in DRFS \) then \( F \cup F' \in DRFS \). Given this property, it would in principle be possible to use the disjunctive resolved feature structures in an implementation without any additional type inferencing procedure to maintain satisfiability. It would, of course, not be very efficient to work with such large disjunctions of feature structures. These disjunctions of feature structures, however, have a singular property: all of the disjuncts have the same shape. The disjuncts differ only in the types labeling the nodes. This property allows a disjunctive resolved feature structure to be represented more efficiently as a single untyped feature structure plus

\[ \text{In fact, it can be shown that if } F \text{ and } F' \in FS \text{ then } R(F) \cup R(F') = R(F \cup F'). \] Unification of sets of feature structures is defined here in the standard way: \( S \cup S' = \{ F \mid F' \in S \text{ and } F'' \in S' \text{ and } F = F' \cup F'' \}. \]
a set of dependent node labelings, which can be further compacted using named disjunction as in Gerdemann [7], Dörre & Eisele [5] or Maxwell & Kaplan [13].

For example, suppose we type resolve the feature structure \( \{ f : \text{bool}, g : \text{bool} \} \) using our encoding of \( \rho \). One can easily see that this feature structure has only two resolvents, which can be collapsed into one feature structure with named disjunction as shown below:

\[
\begin{align*}
\left\{ [f'] , [g'] \right\} & \Rightarrow \left\{ \langle 1 \, t' \rangle \right\} \\
\left\{ f' \right\} & \Rightarrow \left\{ \langle 1 \, t' \rangle \right\}
\end{align*}
\]

We now have a reasonably compact representation in which the FCR has been translated into a named disjunction. However, one should note that this disjunction is only present because the features \( f \) and \( g \) happen to be present. These features would need to be present if we were enforcing Carpenter’s [2] total well typing requirement, which says that features that are allowed must be present. But total well typing is, in fact, incompatible with type resolution, since there may well be an infinite set of totally well typed resolvents of a feature structure. For example, an underspecified list structure could be resolved to a list of length 0, a list of length 1, etc.

Since total well typing is not required, we may as well actively unfill redundant features.\(^5\) In this example, if the \( f \) and \( g \) features are removed, we are left with the simple disjunction \( \{ t', t'' \} \), which is equivalent to the ordinary type \( t \).\(^6\) Thus, in this case, no disjunction at all is required to enforce the FCR. All that is required is the assumption that \( t \) will only be extended by unifying it with another (compact) member of DR.FS.

\(^5\)Intuitively, features are redundant if their values are entirely predictable from the appropriateness specification. See Götz [10], Gerdemann [8] for a more precise formulation.

\(^6\)In this case, it would also have been possible to unfill the original feature structure before resolving. Unfortunately, however, this is not always the case, as can be seen in the following example: \( t[f : +] \Rightarrow \{ t'[f : +] \} \Rightarrow t' \).

This, however, was a simple case in which all of the named disjunction could be removed. It would not have been possible to remove the features \( f \) and \( g \) if these features had been involved in reentrancies or if these features had had complex values. In general, however, our experience has been that even with very complex type hierarchies and feature structures for HPSG, very few named disjunctions are introduced.\(^7\) Thus, unification is generally no more expensive than unification with untyped feature structures.

4 CONCLUSIONS

We have shown in this paper that the kind of constraints expressible by appropriateness conditions can be implemented in a practical system employing typed feature structures and unification as the primary operation on feature structures. But what of more complex type constraints involving reentrancies? Introducing reentrancies into constraints allows for the possibility of defining recursive types, such as the definition of append in [1]. Clearly the resolvents of such a recursive type could not be precompiled as required in Troll.

One might, nevertheless, consider allowing reentrancy-constraints on non-recursively defined types. A problem still arises; namely, if the resolvents of a feature structure included some with a particular reentrancy and some without, then the condition that all resolvents have the same shape would no longer hold. One would therefore need to employ a more complex version of named disjunction (\cite{13}, \cite{5}, \cite{11}). It is questionable whether such additional complexity would be justified to handle this limited class of reentrancy-constraints.

It seems then, that the class of constraints that can be expressed by appro-

\(^7\)Our experience is derived primarily from testing the Troll system on a rather large grammar for German partial verb phrases, which was written by Erhard Hinrichs and Tsuneo Nakazawa and implemented by Detmar Meurers.
priateness conditions corresponds closely to the class of constraints that can be efficiently precompiled. We take this as a justification for appropriateness formalisms in general. It makes sense to abstract out the efficiently processable constraints and then allow another mechanism, such as attachments of definite clauses, to express more complex constraints.

References

[1] Hassan Aït-Kaci. *A New Model of Computation Based on a Calculus of Type Subsumption*. PhD thesis, University of Pennsylvania, 1985.

[2] Bob Carpenter. *The Logic of Typed Feature Structures*. Cambridge Tracts in Theoretical Computer Science 32. Cambridge University Press, 1992.

[3] Bob Carpenter. *ALE The Attribute Logic Engine, User’s Guide*, 1993.

[4] Ann Copestake, Antonio Sanfilippo, Ted Briscoe, and Valeria De Paiva. *The ACQUILEX LKB: An introduction*. In Ted Briscoe, Valeria De Paiva, and Ann Copestake, editors, *Inheritance, Defaults, and the Lexicon*, pages 148–163. Cambridge UP, 1993.

[5] Jochen Dörre and Andreas Eisele. Feature logic with disjunctive unification. In *COLING-90 vol. 2*, pages 100–105, 1990.

[6] Gerald Gazdar, Ewan Klein, Geoffrey Pullum, and Ivan Sag. *Generalized Phrase Structure Grammar*. Harvard University Press, Cambridge, Mass, 1985.

[7] Dale Gerdemann. *Parsing and Generation of Unification Grammars*. PhD thesis, University of Illinois, 1991. Published as Beckman Institute Cognitive Science Technical Report CS-91-06.

[8] Dale Gerdemann. Troll: Type resolution system, user's guide, 1994. Manual for the Troll system implemented by Dale Gerdemann & Thilo Götz.

[9] Dale Gerdemann and Paul John King. Typed feature structures for expressing and computationally implementing feature cooccurrence restrictions. In *Proceedings of 4. Fachtagung der Sektion Computerlinguistik der Deutschen Gesellschaft für Sprachwissenschaft*, pages 33–39, 1993.

[10] Thilo Götz. A normal form for typed feature structures. Master’s thesis, Universität Tübingen, 1993.

[11] John Griffith. *Disjunction and Efficient Processing of Feature Descriptions*. PhD thesis, Universität Tübingen, 1994. Tentative Title.

[12] Paul John King. Typed feature structures as descriptions. In *COLING-94*, 1994.

[13] John T. Maxwell III and Ronald M Kaplan. An overview of disjunctive constraint satisfaction. In *Proceedings of International Workshop on Parsing Technologies*, pages 18–27, 1989.

[14] Carl Pollard and Ivan Sag. *Head Driven Phrase Structure Grammar*. Chicago University Press, Chicago, 1994.