A Linguistic Theory of Robustness *

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1 Introduction

Syntactical robustness is a desired design pro-
perty of natural language parsers. Within the
past decade, several developmental robustness
approaches have been forwarded: Syntax-free se-
mic parsing [1] constraint relaxation after
parse failure in a pattern matching [2] or ATN
framework [3,4], parse tree fitting [5] and several
non-formalized case frame approaches (e.g. the
parser series in [6,7]). Three approaches [5,8,9]
account for special defectivities by extending
grammatical coverage. This paper reformulates
the so-called weakness approach, first published
in [10], which extends robustness to declarative
parsing formalisms.

There are serious shortcomings in robustness re-
search, emerging from the common view of ro-
bustness as a parsing and not as a representa-
tion problem. Typically, two distinct representa-
tion levels for grammatical and non-grammatical
language are assumed. The former is given by
the basic framework, the latter by relaxed pat-
tern slots [2] or ATN arc tests [3], by "non-
grammatical" meta-rules [4], by some construc-
tion specific strategies [6,7] or by the schema me-
chanism [11]. While formalism syntax is somet-
imes specified (e.g. [4,10]), a semantics of robust
grammar formalisms, being necessary to define
these two representation levels, has not been gi-
ven yet. Without a well-defined formalism se-
manics, it is impossible to predict the behaviour
of a (robust) grammar fragment when applied
to non-grammatical language. Therefore, no ro-
bustness methodology has been available until
now.

2 The WACSG approach

WACSG (Weak ACSG) is an experimental for-
malism for defining robust grammars. ACSG
(Annotated Constituent Structure Grammar) is
a class of two-level grammar formalisms such as

LFG [11], DCG [12] and PATR-II [13]. Never-
theless, WACSG weakness concepts may also be
implemented in monostratal formalisms as e.g.
HPSG [14]. WACSG is dedicated to syntactical
robustness, and not to morphosyntactic (spell-
ing correction), semantic or pragmatic robust-
ness. This does not preclude semantics and/or
pragmatics from resolving robustness conflicts.

For a WACSG-grammar fragment to be robust,
its formalism's weakness is necessary but not
sufficient and its adequacy w.r.t. defective lan-
guage is necessary but not sufficient. Robustness
theory is to show that defective language is ex-
actly the language described by "weak" descrip-
tion methods. Any less metaphorical construc-
tion of the notion of weakness needs a conside-
rable formal apparatus.

3 The WACSG Formalism

A WACSG grammar rule is a context free pro-
duction annotated with an attribute-value- (av-
) formula. The following two subsections deal
with weakness relations for context free gram-
mars and av-languages. Section 3.3, then, speci-
ifies the WACSG formalism semantics.

3.1 Partial String Languages

Below (1), three partial string languages of a context-
free grammar $G = < \text{Cat}, \text{Lex}, \text{Pr}, \text{Sset} >$ are
defined, where Cat and Lex are sets of nonter-
minal and terminal symbols, respectively, Pr a
set of productions and Sset a set of start sym-
ols. Now let $P_w$ a set of substrings of $w$ and
$PP_w$ a set of power-substrings of $w$ with any
$w' \in PP_w$ resulting from deletion of arbitrary
substrings in $w$. If $|w| > 0$, then $P_w$ and $PP_w$
must not contain $\epsilon$. $Z_w$ and $ZZ_w$ are par-
tion functions in $P_w$ and $PP_w$, respectively. More
simply, $SET(G)$ equals $L(G)^*$. $SUB(G)$ allows
an undefined leftside and/or rightside substring
and $PAIR(G)$ even undefined infix substrings for
every element from $L(G)$.

(1)
\[ \text{SET}(G) = \{ w \in \text{Lex}^+ \mid \exists n \in \mathbb{N} \exists z \in I^n_w \cap L(G) \} \]

\[ \text{SUB}(G) = \{ w \in \text{Lex}^+ \mid \exists n \in \mathbb{N} \cap L(G) \} \]

\[ \text{PAR}(G) = \{ w \in \text{Lex}^+ \mid \exists n \in \mathbb{N} \cap L(G) \} \]

Partial string languages have appealing formal properties: \( \phi(G) \) for \( \phi \in \{ \text{SET}, \text{SUB}, \text{PAR} \} \) is context-free, contains \( \text{ciff} \) \( L(G) \) contains \( \text{c} \) and there is an order \( L(G) \subseteq \text{SET}(G) \subseteq \text{SUB}(G) \subseteq \text{PAR}(G) \). Nesting partial string languages introduces a set \( \Phi(G) \) of languages such as e.g. \( \text{SET} (\text{SUB}(G)), \text{SET} (\text{PAR}(G)) \). We have \( |\Phi(G)| = 1 \), i.e. all languages with maximal operator \( \phi \) are weakly equivalent, though not pairwise strongly equivalent.

A recursive partial string grammar (RPSG) is obtained by indexing rightside (nonterminal) symbols of a cfg \( G \) with indices \( \text{SET}, \text{SUB}, \text{PAR} \). The formalism-semantics for an RPSG is given by a derivation relation (cf. [15]) for non-indexed and \( \text{SET} \)-indexed nodes of a tree graph and by a generation function \( \text{gen}_\omega \) as displayed in (2) for any other nodes. Let \( \Omega(G) \) the set of derivations for a given \( G \), \( w \in \Omega(G) \) a derivation and \( t_0 \) its tree graph. Let \( t_0 \) be a label function with \( L(t_0(0)) \subseteq \text{Ssetind} \) a (possibly indexed) start symbol. The languages \( L(G) \) (derived language) and \( \text{RPSL}(G) \) (generated language) are defined in 3. \( L(G) \) and \( \text{RPSL}(G) \) are context-free and we have \( L(G) \subseteq \text{RPSL}(G) \).\( L(G) \) usually being much smaller than \( \text{RPSL}(G) \).

\[ \text{gen}_\omega : t \times (\text{Catind} \cup \text{Lex})^+ \rightarrow \{0, 1\} \]  

(3)

Let \( G \) be a RPSG.

\[ \text{L}(G) = \{ w \in \text{Lex}^+ \mid \exists \phi \in \text{Ssetind} \phi \rightarrow \rightarrow w \} \]

\[ \text{RTSS}(G) = \{ w \in \text{Lex}^+ \mid \exists \omega \in \Omega(G) \text{gen}_\omega(0, w) = 1 \} \]

3.2 Attribute-Value Languages

The av-language \( \partial \) is a first order predicate logic including 1-ary function symbols and two 2-ary predicates "\( \approx \)" and "\( \varepsilon \)" for equality and set membership, respectively. Soundness and completeness of \( \partial \) without \( \varepsilon \) has been proven in [16]. The predicate "\( \varepsilon \)" introduces well-founded, distributive, recursive sets of attribute-value-structures, and is discussed in [17]. We assume the existence of a reduction algorithm \( \text{RNF} \) with \( \text{RNF}(A) \in \partial \) iff \( A \) is satisfiable and \( \text{RNF}(A) = \bot \) otherwise. The classical subsumption \( \subseteq \) gives a partial ordering within the set of av-models. There are, however, no inconsistent models. Therefore, a partiality notion with inconsistency must be based upon descriptions i.e. av-formulae. The relation 3-partial \( \subseteq \partial^2 \) is a subsumption-isomorphism into a (canonical) subset of \( \partial \). The relation 0-partial defined below is still weaker in allowing inconsistency of one formula \( B \) and can be shown to be a superset of 3-partial, i.e. 3-partial \( \subseteq \) 0-partial.

Let \( I \in \partial \) a conjunction of literals, and \( A, B \in \partial \). Then \( A \) 0-partial \( B \) iff:

1. \( \text{RNF}(A \land I) \neq \text{RNF}(A) \)
2. \( \text{RNF}(A \land I) = \text{RNF}(B) \), if \( \text{RNF}(B) \neq \bot \)
3. \( \text{DNF}(A \land I) \neq \text{DNF}(B) \) otherwise

3.2.1 Set weakening

In robustness theory, the purpose of av-sets is to weaken the condition on av-structures. Set weakening may be used e.g. for the transition from an inconsistent formula \( A \approx x \text{(syn)(case)} \approx \text{nom} \land x \text{(syn)(case)} \approx \text{akk} \) to a consistent (therefore non-equivalent) formula \( A' \approx \text{syn}(\text{case}) \approx x_1 \approx \text{nom} \land x_2 \approx \text{akk} \land x_1 \in x \text{(syn)(case)} \land x_2 \in x \text{(syn)(case)} \). This transition preserves case information, but not inconsistency for the denotatum \([x_2]\). In general, set weakening is defined as follows:

(4)

Let \( A \in \partial \) a formula in disjunctive normal form and \( t \) a non-constant term. Let \( L_G = \{ A_{i,j,k} \mid t \text{ occurs } k \text{-times in a literal } A_{i,j} \} \) a set of indices. For any \( r \in L_G, z_r \) is a variable not occurring in \( A \). The set weakening of \( A \) for a term \( t \) is \( A^t = (A[t'/z_r] \land \forall w, z_r \in t \epsilon L_A) \). For any \( A \in \partial \) and non-constant term \( t \) it has been shown (see [17]) that, if \( \text{RNF}(A) = A \neq \bot \), then also \( \text{D} \text{NF}(A^t) = \text{RNF}(A'^t) \neq \bot \). Therefore, if \( A \) is satisfiable, then \( A^t \) is also satisfiable. Since satisfiability of \( A \) does not follow from satisfiability of \( A' \) (see above), \( A^t \) is weaker-or-equivalent to \( A \).

3.2.2 Defaults

The classical subsumption \( \subseteq \) gives a partial ordering within the set of av-models. There are, however, no inconsistent models. Therefore, a partiality notion with inconsistency must be based upon descriptions i.e. av-formulae. The relation 3-partial \( \subseteq \partial^2 \) is a subsumption-isomorphism into a (canonical) subset of \( \partial \). The relation 0-partial defined below is still weaker in allowing inconsistency of one formula \( B \) and can be shown to be a superset of 3-partial, i.e. 3-partial \( \subseteq \) 0-partial.

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3. \( \text{DNF}(A \land I) \neq \text{DNF}(B) \) otherwise

Robustness in the area of av-languages is the ability to cope with inconsistent (i.e. overspecified) formulae. Two different methods for maintaining consistency will be considered, namely set weakening and default formulae.
3. $RNF(A) \neq \bot$

The formula $I \in \partial$ may be restricted to be a conjunction of default literals, whose predicate is marked with a subscript $a$. This gives a default relation, which is a subset of a superset of subsumption between formulae. A relation of default-satisfiability $\vdash \models a$ may be based upon this default relation. It is easy to demonstrate that a default relation like this has some desired disambiguation properties: a disjunctive formula $A = A_1 \lor A_2$ is reduced to $RNF(A_1 \land I)$ by conjoining it with a default formula $I \models a$ such that $RNF(A_2 \land I) = \bot$.

4 WACSG formalism semantics

For any WACSG-Grammar $G$, a domain $D(G)$ and its subset $SDDE(G)$ of strictly derivable domain elements is defined as follows. Any domain element not in $SDDE(G)$ bears weakness relations to a derivation $\omega \in \Omega(G)$, where $\omega(0)(1) \in Sset_{md}$. Any formula $\omega(i)(2)$ ($0 \leq i \leq |\omega|$) may be inconsistent. Now, a grammar $G$ is called weak iff $D(G) - SDDE(G) \neq \emptyset$.

(6)

Let $G$ be a WACSG grammar, $G^k$ the cf base of $G$ and $\omega^k$ the cf part of a derivation $\omega \in \Omega(G)$. Let $M$ be the set of av-models.

- $D(G) = \{ < \omega, M > \in Lex^+ \times M | \exists \omega \in \Omega(G)$
  1. $\omega \in RPSL_{\omega^k}(G^k)$
  2. $M \models \omega(\omega)(2)$
- $SDDE(G) = \{ < \omega, M > \in Lex^+ \times M | \exists \omega \in \Omega(G)$
  1. $\omega = \omega(\omega)(1)$
  2. $M \models \omega(\omega)(2)$

Default-formulae and set membership formulae cannot be simulated by anything else in WACSG formalism. For every WACSG grammar $G$, however, there is an equivalent WACSG grammar $G'$ without any partial string indices within it. This grammar $G'$ shows an extreme complexity already for a few indices in $G$. This fact challenges the view (see e.g. [8]) that robustness can be achieved by coverage extension of any non-weakeal ACMG.

5 A WACSG-treatment of restarts

In this section, the WACSG formalism is applied to restarts, a class of spoken language constructions, which is often referred to in robustness literature [2,3,4]. A grammatical explanation, however, is still lacking. The German restart data in 7 are given with transliteration and segmentation. Constructions in 7,8 are ungrammatical, but not unacceptable.

(7) die [Umschaltung $A$ Einstellung] des Fonts
the [switching $A$ adjustment] of the font
$\alpha \beta \beta' \gamma$

(8) Peter [versuchte dann $A$ konnte] kommen
Peter [tried then $A$ could] come
$\alpha \beta \beta' \gamma$

From the viewpoint of robustness theory, a restart $< \alpha\beta A\beta'\gamma, M > \in D(G)$ should not be in $SDDE(G)$ exactly if it is defect, where $G$ is a realistic WACSG fragment of the language in question. Roughly, restarts are a kind of phrasal coordination not allowing for deletion phenomena such as ellipsis, gapping or left deletion. Additionally, the $\beta$-substring (i) does not contribute to (extensional) meaning of the construction and, (ii), may show recursive defectiveness such as contamination and constituent break (examples 9,10).

(9) daß er [dieses Meinung $A$ dieser Meinung] ist
that he [this-neuter opinion-fern A this-fern opinion-fern] has

(10) Peter ist [ins in das $A$ dann Vater gewesen]
Peter is [in-the in the A then father been]

5.1 NP-restarts

The following WACSG rules 11-14 deal with openly coordinated NP restarts and are easily generalized to prepositional, adverbial or adjectival phrase restarts. Under the coordination hypothesis, a parallelism between defective and non-defective restarts is assumed. Right-recursecive coordination of defective and nondefective conjuncts is unrestricted. In 11, equations simulating semantic and syntactic projections (see [18]) "control up" the syntactic but not the semantic description of a $\beta$ conjunct in a restart construction.

In rules 13,14, partial string indices $\text{subj}_{\beta}$ and $\text{par}$ allow a defect conjunct to cover a prefix substring (if no phonological restart marker of category AC is present) or every substring (if there is a restart marker).

However, it does contribute to meaning in an intensional sense: $\beta$-substrings are not absurd.
Rule 11 applies set weakening to the syntactic av structures of both conjuncts, resulting in a well-known coordination treatment [19]. Default equations provide disambiguation to syntactic features \([x_1(syn)(case)]\) and \([x_1(syn)(gender)]\), since defectivity may render the first conjunct ambiguous.4 Furthermore, rule 15 shows default weakening of the syntactic description of NP’s.

\[
\begin{align*}
(11) \ NP & \rightarrow \ NPC \ NP \\
x_1(syn) & \approx x(syn) \land \\
x_1(syn)(gender) & \approx_d \text{mas} \land \\
x_1(syn)(case) & \approx_d \text{nom} \land \\
x_2(syn) & \approx x(syn) \land \\
\vee x_1(syn)(koord)(sy4(defec)) & \approx + \land \\
x_2(syn) & \approx x(syn) \land \\
x_2(syn)(koord) & \approx - \land \\
x_2(syn)(koord)(sem) & \approx x_1(syn)(koord)(sem) \land \\
x_2(syn)(koord)(defec) & \approx x(syn)(koord)(defec) \\
\end{align*}
\]

\[
(12) \ NPC \rightarrow \ NP \ CO \\
x_1(syn)(koord) & \approx x(syn) \land \\
x_2(syn)(koord) & \approx x(syn)(koord) \land \\
x_2 \approx x(syn)(koord) \\
\]

Example C1 (appendix) shows a complex NP-coordination of defective and non-defective conjuncts. The conjunct NP des Peter shows a contaminated case feature, since des has genitive and Peter has nominative, accusative or dative morphological case marking. Nevertheless, remark that \([0.2.1(syn)(case)]\) is disambiguated to nominative in the av-structure in C1.

5.2 VP-restarts

Although VP-restarts follow the same lines as NP-restarts, open coordination of defective conjuncts imposes additional problems 5:

- Within a simulated projection theory, controlling down a verbal argument into a vcomp-embedded element of an av-set requires a complex regular term \(x(syn) + (vcomp)(syn) + \), which is expensive to compute. Therefore, rules 16,18 introduce an additional term \(x(kosem)\), such that \([x(kosem)]\) is the semantic structure of a set \([x]\) of openly coordinated av-structures. By default satisfiability of \(x(kosem) \approx x(kosem)\), \([x(kosem)]\) equals \([x(kosem)]\) except if \([x]\) is the av set of a non-restart coordination.
- Since defectivity, e.g. a constituent break, may render incomplete the \(\beta\) verbal phrase incomplete, rule 17 provides default semantic values for every possible semantic argument.
- Distributed av formulae may be necessary for one conjunct but inconsistent with (the description of) the other. This situation may arise due to contamination of the first (\(\beta\)) conjunct. Independently it can be shown that contaminations almost exclusively affect syntactic (as opposed to semantic) features. Now, if the conditions coherence and completeness (see [11]) are defined on semantic structure, syntactic coherence can be enforced by lexicalized formulae as shown in 19 that depend on a syntactic defectivity feature \([x(syn)(defec)]\).
The example C2 (appendix) involves a distributed av-structure, whose description is inconsistent with respect to syntactic case subcategorization of \( \beta \)'s finite verb \( \text{gefällt} \).

6 Conclusion

The reformulation of robustness theory as a theory of weak grammars (and, consequently, of robust parsing as parsing of weak grammars) has enabled both the specification of working parsers \([17]\) and a substantial explanation of non-grammatical languages. Further study has to be done. Cross-linguistic research on defective constructions (e.g. non-grammatical ellipses) and a default logic matching methodological standards of AI theory remain important desiderata. Our prediction that there is no strong theory of defectiveness, however, invites for falsification.

7 Bibliography

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Appendix

(C1)

dieser also der A des Peter und die Maria
this therefore the-gen A the-gen Peter and the Mary
den Peter [gefällt A interessiert die Schule sehr]
the-akk Peter [likes (with no akk argument) A is-interested-in the-akk school very]