Extending the HPSG Grammar Matrix with Richer Lexical Semantics

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Abstract

This paper presents an implementation of extended qualia structures in a contemporary HPSG formalism. The extended qualia structures employ a vocabulary of semantic roles and a fifth quale for shape or contour. Motivation for such extensions is given on different grounds, and some ideas as to how to derive the additional information automatically, are presented.

1 Introduction

The HPSG Grammar Matrix (Bender et al., 2002) is an extraction of the language-independent types from the English Resource Grammar (Flickinger, 2000) and presents a detailed and, in most respects, widely accepted elaboration of the standard HPSG formalism (Pollard and Sag, 1994).

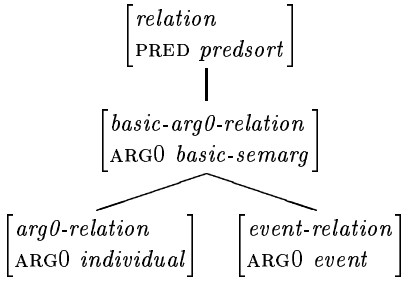
The feature geometry of lexical semantics in the HPSG Grammar Matrix is rather simplistic. The type hierarchy of relations is extensive and introduces a variety of relations types, but lexemes only introduce such relations on difference lists, i.e. unordered "bags" of relations (Copestake et al., 1999). The empirical motivation for a richer lexical semantics includes the semantics of adjectives (Pustejovsky, 1993; Larson, 1998), compound nouns (Johnston and Busa, 1999), possessives (Vikner and Jensen, 2002) and prepositions (Mari and Saint-Dizier, 2004). Research on related phenomena has led to the formulation of a structured lexicon and various accompanying mechanisms which exploit these structures so as to account for the generative nature of the lexicon (Pustejovsky, 1995).

One of the central structural components of the generative lexicon is qualia structure. The present paper concentrates on the implementation of this component in the framework of the HPSG Grammar Matrix. Some obvious concerns include a minimal extension of the original feature geometry and maximal use of type inference, in the sense of (Flickinger, 2000).

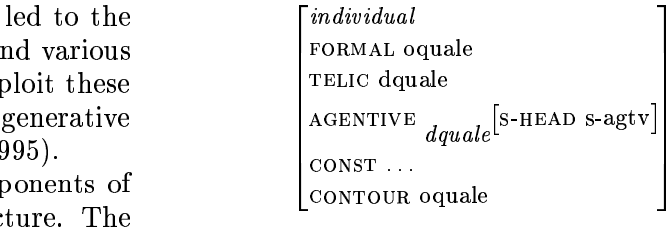
Despite our concerns about minimality, our implementation extends qualia structure with a fifth quale and a vocabulary for semantic roles. Since this is a serious complication, the major part of this paper is devoted to the motivation of the associated features.

2 Feature geometry

In the HPSG Grammar Matrix, semantic relations are partially defined by the following type hierarchy:

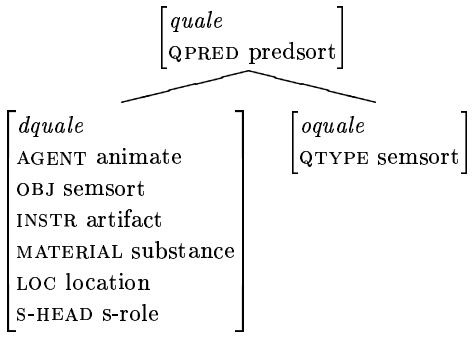


The type *individual* is furnished with a SORT attribute intended to specify sortal restrictions (for pronoun resolution, animateness, etc.). Since this information is already contained in conventional qualia structure, we insert qualia structure as a set of features on this type. The preliminary feature geometry is presented here:[1]

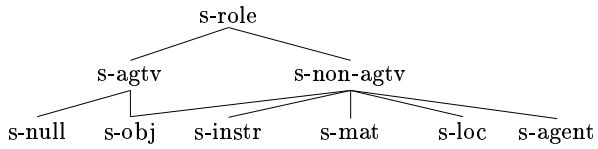


[1] Efficient implementation of constitutive qualia raises a number of interesting problems. Since this paper focuses on the extension of traditional qualia structure, the issue is ignored for now.

Qualia are encoded as two types of complex feature structures. These structures are defined in the following type hierarchy:[2]



The agentive and telic qualia inherit a number of semantic roles (Σ-roles) and a feature S-HEAD (Σ-head). The possible values of S-HEAD are defined by this hierarchy:



The notion of Σ-head functions much like indexing in the original formulation of qualia structure (Pustejovsky, 1995). If e.g. the telic quale of *knife* includes the feature [QPRED *cut*] and adequate sortal restrictions on semantic roles, it is still necessary to specify what semantic role is linked to the index of *knife*. In (Pustejovsky, 1995), this is expressed by coindexation. Unfortunately, this leads to cyclic embedding, since the index of *knife* is a value of one of its embedded features. Instead the S-HEAD feature is used to constrain the linking of indeces with semantic roles in composition. The partitioning of the set of Σ-head values into *s-agtv* and *s-non-agtv* illustrates the fact that only a subset of Σ-head values are relevant in agentive contexts.

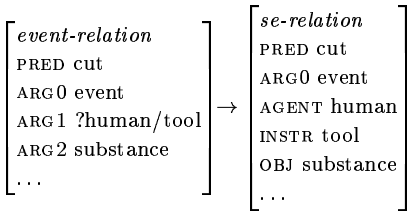
Formal and contour qualia inherit another set of types, i.e. QTYPE. This feature corresponds to SORT in that it is used to specify sortal information about a semantic type. It is now possible to extract from the qualia structure both a sortal and predicative use of formal qualia.[3]

[2] QPRED has the same meaning as PRED, but the feature is renamed to be introduced at this level of the feature geometry for technical reasons.

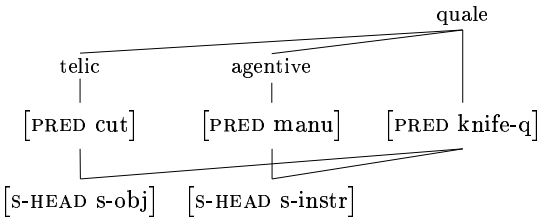
[3] The predicative use of formal qualia is not discussed in this paper. Briefly, it has been used to compose the semantic forms of coordinative and copulative constructions, e.g. (Søgaard, 2004).

The feature geometry as presented here is a complication of the general feature geometry of the HPSG Grammar Matrix. It is natural to ask if some "tightening up" is possible?

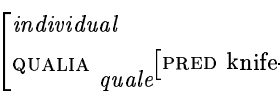
Consider again the hiearchy of relations. The *event-relation* is instead replaced by a new type *se-relation*, introducing the same set of features as *dquale*. This extends the Σ-vocabulary to every event relation; for some motivation, see (Parsons, 1991). The translation from *event-relation* to *se-relation* is exemplified below. The question mark illustrates how semantic roles are often more natural to encode:



Now say *quale* is a subtype of *se-relation*. The feature geometry is then already simplified in that no duplication of PRED values is needed. The feature geometry is further simplified by exploiting type inference. Consider the following type hierarchy:



The hierarchical ordering of qualia is well-formed, since the predicates are themselves hiearchically ordered, i.e. *cut* is a subtype of *knife-q*.[4] From the lexicographer's point of view, this is kind of backwards. Each time a lexical entry points to *cut* in its qualia structure, its qualia value (e.g. *knife-q*) should be added to the supertype of *cut*. The partial lexical entry of *knife* can then be simplified:



[4] The introduction of predicate values in the type hierarchy is not a standard feature of the HPSG Grammar Matrix. For technical reasons, this move is also necessary for generation in the LKB grammar engineering system. See (Copestake, 2004) for details about generation in the LKB system.

The advantage of the new hierarchy is that in the feature geometry, agentive and telic qualia can be collapsed. If in a certain context, the telic aspect of *knife* is modified, the QUALIA value is simply unified with *telic*, and the telic qualia of *knife* is inferred. The special constraint on agentive contexts is simply added to the type *agentive*.

In sum, our feature geometry differs from that of (Pustejovsky, 1995) in a number of respects, i.e.:

(i) it introduces qualia structure at the level of *individual*,

(ii) it conflates type information and the formal role,

(iii) it conflates agentive and telic qualia in the feature geometry,

(iv) it introduces the S-HEAD feature for agentive and telic qualia,

(v) it distinguishes betwen sortal and predicative use of formal qualia,

(vi) it adopts a vocabulary of semantic roles rather than specifies the arity of qualia predicates,

(vii) and it introduces a fifth quale for contour.

Some objections to (i) and (iii) are presented in the final section. (ii), (iv) and (v) are ignored for the rest of the paper. Instead the following sections are devoted to the motivation of (vi) and (vii).

3 Σ-roles

Our theory of Σ-roles is inspired by Dik's *Semantic Function Hierarchy* (Dik, 1978). The hierarchy is extended with a role for materials. Each role is conceived of as an *event participant role*:

Agent ≫ Object (Goal) ≫ Recipient ≫ Beneficiary ≫ Instrument ≫ Material ≫ Location

Dik's *Goal* is renamed as *Object* (in order not to confuse *Goal* with *Recipient*!). In addition, we collapse *Location* and *Temporal* into a notion of spatio-temporal *Location*.[5]

[5]The exact translation of this vocabulary was motivated by the study of compound semantics (Søgaard, 2004), but I wish to stay agnostic about the exact number of roles and their labels and interpretations. See (Parsons, 1991) for some discussion.

3.1 Linguistic motivation

In the functional-typological literature, the relevance of semantic roles to linking is often recognized, see e.g. (Dik, 1978; van Valin and LaPolla, 1997), but the following data is supposed to explicitly motivate semantic roles in qualia structures:

In agentive or telic compounds, both constituents occupy a Σ-role by hypothesis; but some roles are more natural than others. In some languages, the modifier only takes a restricted number of roles. Consider the following compound nouns from Danish:

(1) (a) eskimomusik ('Eskimo's music')
(b) eskimokniv ('Eskimo's knife')
(c) kunstnerværksted ('artists' workplace')
(d) børneler ('children's clay')

In (1), the referents of the modifiers all participate as agents in the events inferred from the lexical semantics of the head nouns, but while the referent of the head noun in (1a) is the object of its respective event, that of (1b) is an instrument. In (1c), the referent of the head noun is the location, while in the fourth example, (1d), the head noun's referent participates as material.

This kind of analysis constitutes no positive evidence for the theoretical status of Σ-roles. The real evidence comes from the ungrammaticality of certain combinations of roles in certain languages.[6] Here are some examples:

In English, the combination of agents and instruments (in that order) in agentive or telic contexts is ungrammatical:[7]

(2) *butcher knife

while in Danish, the reverse order of the same two roles is ungrammatical:

(3) *knivslagter ('knife butcher')

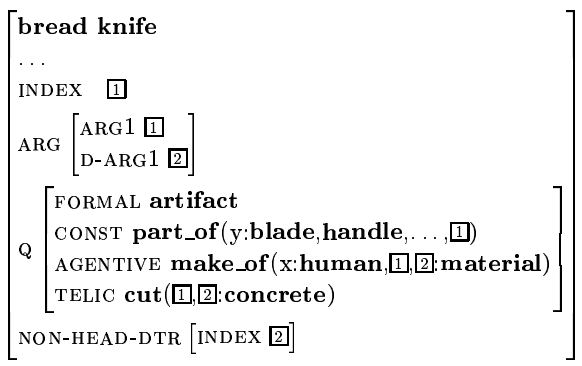
[6]This kind of reasoning is also found in (Copestake, 1999) who concludes that "limitations on generativity provide the best arguments for a (semi-)generative lexicon."

[7](Copestake and Lascarides, 1997) argue the proper restriction in fact relates to the SORT value of the modifier noun, i.e. they simply claim that modifier nouns must be $\left[\text{SORT } \textit{non-human}\right]$. See (Søgaard, 2004) for discussion.

Additional motivation comes from cross-linguistic comparison. (Johnston and Busa, 1999) find suggestive data for a qualia-based analysis of compound semantics in a comparison of Italian and English compound nouns. Briefly, they observe that in Italian, compounds such as *ice knife* are disambiguated by the prepositional linking elements:

(4) (a) coltello di ghiaccio ('knife made of ice')
(b) coltello da ghiaccio ('knife for cutting ice')

The basic idea of (Johnston and Busa, 1999) is that in compound interpretation, the index of the modifier is unified with the default argument in the argument structure of the head daughter. In the head daughter, the default argument is again unified with arguments in the qualia structure. In their notation:



Consider the compound *kitchen knife*. Since the modifier denotes a location, one might be tempted to simply translate *kitchen knife* into **loc(knife,kitchen)**. Consider the Italian translation:

(5) coltello da cuccina

On Johnston and Busa's account, (5) is a telic compound. This corresponds to the intuition that a *kitchen knife* is not a knife made in a kitchen, but a knife to be used in a kitchen. In addition, a compound of the logical form $\mathbf{loc}(\beta, \alpha)$ does not translate consistently into *da*-constructions. In fact, such compounds are typically translated into compounds with the prepositional linking element *per* (Paggio and Ørsnes, 1993). Consequently, it seems right to insist that (5) is really telic of nature. Unfortunately, there is no way to link the index of *kitchen* to the telic predicate in the qualia structure of *knife*. This of course is remedied once Σ-roles are introduced.

4 The contour quale

The motivation for the fifth quale includes a philosophical argument, some facts about compound semantics, some evidence from first language acquisition and observations about strong selectional restrictions in modification of nouns. In addition, it is demonstrated that the cost of adding this fifth quale to existing qualia lexicons is likely to be very small.

4.1 Philosophical motivation

The notion of qualia originates with Aristotle's *Physics* (Pustejovsky, 1995), but what Pustejovsky calls formal qualia is in fact described by (Aristotle, 1999) as "the essential form or image" of something. It seems Aristotle envisaged that the form or contour of an object was indeed one of its necessary causes. Intuitively, this makes sense, since reasonable answers to a question of the form "what is x?" include:

(a) it's a y (if x is a kind of y)
(b) it's something made of ...
(c) it's something used for ...
(d) it's something constituted by ...
(e) it's something that looks like ...

The five answers correspond to five qualia, respectively formal, agentive, telic, constitutive and contour qualia. Of course there are other ways to answer such a question depending on what kind of thing x is, e.g. if it is a musical instrument an answer of the form "it sounds like ..." is likely. If (a-e) are in fact the most prominent strategies could be tested experimentally.

4.2 Linguistic motivation

In English, many compound nouns of the form $\alpha\beta$ are interpreted "β that looks like an α". Consider, e.g.:

(6) guitar fish

It has been proposed, e.g. by (Bauer, 1979), that compounds such as (6) are semantically underspecified and undergo some sort of pragmatic resolution. One counterexample to such an approach is the consistent ungrammaticality of such compounds in certain languages. Estonian e.g. is one such language (Hiramatsu et al., 2000):

(7) *nasi tool ('hand chair')

(Hiramatsu et al., 2000) tested English and Estonian language users' acceptance and production of similar compounds. The English subjects produced contour-based compounds freely, while Estonian language users were quite reluctant to do so.

4.3 Language acquisition

In first language acquisition studies, it has often been noted that children categorize by means of shape (Landau et al., 1988; Imai et al., 1994). This phenomenon is referred to as "shape-bias", but suggests the importante of contour when determining the extension of nouns. The shape-bias is generally believed to be activated at an early age, and researchers in language acquisition have independently speculated if "this is a reflection of the structure of the language children hear" (Samuelson, 2000).

4.4 Selectional restriction

If one believes in grammatical encoding of selectional restrictions, contour seems as relevant a feature as any other. Some sortal restrictions are not easily formulated without reference to contour. Consider, for example:

(8) ?en høj bold ('a high ball')

5 Automatic extension of qualia lexicons

Automatic extraction of qualia information from machine readable lexicons has been explored by various researchers (Copestake, 1990; Hayes, 2001). In addition, qualia lexicons have been manually written for a number of European languages, i.e. the SIMPLE dictionaries (Lenci et al., 2000). SIMPLE entries are easily converted into HPSG Grammar Matrix format (Søgaard, 2004). So it seems that we have all the tools necessary for extending the HPSG Grammar Matrix with richer lexical semantics for actual applications, except for one thing: No method for extracting information about Σ-roles and contour qualia from linguistic resources is currently available.[8]

However, extraction of contour information from dictionaries seems relatively straightforward. Consider the following experiment on a Danish machine readable dictionary:

All entries (129) with the genus term *beholder* ('container') were extracted from the electronic version of *Den danske ordbog* (Hjort and Kristensen, 2003).[9] Contour descriptions were identified. Only descriptions that could be extracted as predicates were included, e.g. *cylindrisk* ('cylindrical'), but not *med stive sider* ('with stiff sides') or *med hank og tud* ('with handle and lip'). In addition, very vague adjectives like *åben* ('open') or *lille* ('small') were excluded. Consequently, contour descriptions were either geometrical terms or *-formed*-formations.

The entries included 54 compounds of which 17 had separate contour information. The remaining 37 compounds were all endocentric compounds whose contour information can be derived from information about the head noun. However, contour information was only found in the lexical entries of the head nouns in 17 cases. Consequently, out of 129 entries, 71 contained information about contour, but 20 of the entries without contour information were endocentric compounds, and contour information can thus be derived from the entries of their head nouns, once this information is included in the lexicon. The result is summarized in the table below.

Contour	Compound	#
-	-	38
-	+	20
+	-	54
+	+	17
Total		**129**

Simple extraction from a machine-readable dictionary allows us to extract contour information from approx. 55% of the entries. The remaining 45% will inherit the contour information from *beholder*, i.e. roughly, *three-dimensional*. The extraction is easily improved by searching multiple dictionaries, e.g. *Nudansk ordbog* (Becker-Christensen, 2001) has contour information for some of the words with no information in *Den danske ordbog*. In addition, some definitions refer to subconcepts of *beholder*

[8] Technically, qualia is no longer encoded in the lexicon, but in the type hierarchy. In terms of automatic extraction of information, this has no interesting consequences.

[9] The present experiment uses the available linguistic resources for Danish. Since many languages have more available resources, it is likely that more succesfull experiments can be performed for such languages. The intuition remains the same, however. Dictionary entries often contain contour information, e.g. *suitcase* is defined as 'a large rectangular case with a handle for carrying clothes and possessions while travelling' in *Cambridge Advanced Learner's Dictionary* (Woodford, 2003). The search can be optimized by considering and comparing multiple resources and utilizing basic linguistic structures.

which are listed in the dictionaries with explicit contour information. If a combined search in the two dictionaries and this kind of inheritance was pursued, the success rate would ideally increase to 78%.[10] While this experiment was very informal, it still suggests that contour information will prove one of the easier subtask in the enterprise of automatic construction of qualia lexicons.

The sortal restrictions on Σ-roles can also be semi-automatically acquired, though this seems to be more cumbersome. See (Gildea and Jurafsky, 2002) for relevant discussion and similar work. In reality, it may be that only the values of OBJ attributes need to be further restricted (since most roles are only filled by specific kinds of things, e.g. agents are humans). This information can probably be extracted from WordNet, see e.g. (McCarthy and Carroll, 2003).

6 Objections

6.1 Coreference

Various objections may be raised at this point. The extension in (i) at page 3 may have unwanted consequences. If *individuals* with embedded qualia structures are unified for coreference, the qualia structures must of course be compatible. This is unproblematic for pronoun resolution, but what happens when definites refer to discourse referents? Consider (9). Or what happens in coordinative constructions, e.g. (10)?

(9) The university in Trondheim$_i$ is beautiful. The building$_i$ was built ...

(10) actor-producer

If dotted objects (implemented as supertypes with abstract qualia structure) are assumed, (9) is unproblematic, theoretically. However, the example illustrates that if qualia structure is implemented on *individual*, this strongly constrains qualia annotation. It is necessary to always check which qualia structures are compatible with which. If this is at all possible is of course an empirical issue. Examples like (10) seem to suggest it is not. If so, qualia structure must be moved to somewhere else in the feature geometry.

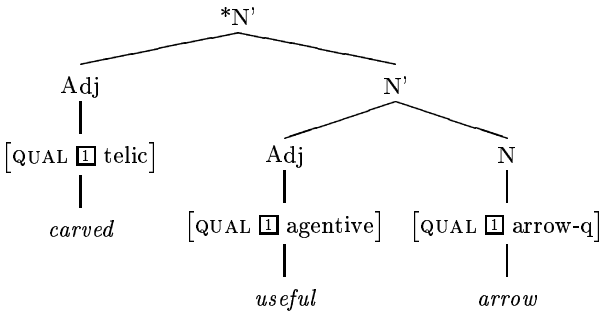
[10] This result was obtained by manual inspection. 20 of the entries with no contour information were of words not included in *Nudansk ordbog* and were thus excluded. Of the remaining 38 entries for which no contour information was found on the first search, contour information was supplied for 14, i.e. 10 non-compound words and 4 compounds. Consequently, the numbers change to 85/109.

6.2 Multiple-facetted modification

Pustejovsky (2001) presents the hypothesis that every phrase occuring as a modifier to a nominal head is associated with a specific qualia role. He then presents empirical data to demonstrate how modifiers can simultaneously modify different qualia roles, e.g.:

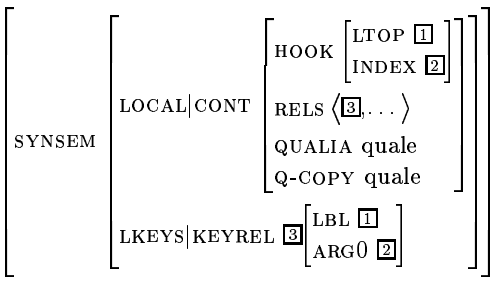
(11) a large carved wooden useful arrow[11]

On Pustejovsky's account, the first adjective modifies the formal quale of the noun, the second adjective the agentive quale, the third adjective the constitutive quale, while the fourth and last adjective modifies its telic quale. Is this kind of multiple-facetted modification consistent with our inference-based implementation of qualia roles? Consider this (simplified) tree:



The tree is illformed, since *telic* and *agentive* do not unify. Unfortunately, the unifications follow from the unification of the indeces of the three constituents. There is no obvious way to avoid this. It doesn't solve the problem to move the QUALIA attribute out of *individual* (see above), since qualia still need to percolate from the head-daughter to be accessible for other modifiers. Only if a "copy" of the qualia structure is made, and this copy is specified to percolate can (iii) be uphold. It seems this leaves us with two solutions. Either (i) is abandoned and a "qualia copy store" (Q-COPY) is introduced in the feature geometry; or the original design (page 1) is restored. The first solution results in the following feature geometry:

[11] While this example may sound somewhat odd, the combination of *carved* and *wooden* are in fact often combined in a single prenominal field.



The duplication of qualia information is unpretty. Since the use of type inference has some radical consequences for the underlying lexical ontology (see above), and more generally, since the second solution is more conservative than the first one, we tentatively suggest to maintain the original feature geometry with the extensions presented here. Since this complication bears on the existence of multi-facetted modification, this phenomena should be subject to future research.

7 Conclusions

The paper discussed the implementation of qualia structure in the HPSG Grammar Matrix feature geometry and some extensions to standard qualia structure. The extensions relate to semantic roles and additional qualia and were motivated by empirical and experimental data as well as theoretical and practical considerations. It was also demonstrated how the extensions are relatively uncostly for applications.

8 Acknowledgements

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References

Aristotle. 1999. *Forelæsninger over fysik [Physics]*. Gyldendal, Copenhagen.

Lauri Bauer. 1979. On the need for pragmatics in the study of nominal compounding. *Journal of Pragmatics*, 3:45–50.

Christian Becker-Christensen, editor. 2001. *Nudansk ordbog*. Politiken.

Emily M. Bender, Daniel P. Flickinger, and Stephan Oepen. 2002. The grammar matrix: an open-source starter-kit for the rapid development of cross-linguistically consistent broad-coverage precision grammars. In *Proceedings of the Workshop on Grammar Engineering and Evaluation at the 19th International Conference on Computational Linguistics*, Taipei, Taiwan.

Ann Copestake and Alex Lascarides. 1997. Integrating symbolic and statistical representations: the lexicon-pragmatics interface. In *Proceedings of ACL-EACL 1997*, Madrid, Spain.

Ann Copestake, Daniel P. Flickinger, and Ivan A. Sag. 1999. Minimal recursion semantics: an introduction. Manuscript, Stanford University: CSLI.

Ann Copestake. 1990. An approach to building the hierarchical element of a lexical knowledge base from a machine readable dictionary. In *Proceedings of the 1st International Workshop on Inheritance in Natural Language Processing*, Tilburg, Germany.

Ann Copestake. 1999. The semi-generative lexicon: limits on lexical productivity. In *Proceedings of the 1st International Workshop on Generative Approaches to the Lexicon*, Geneva, Switzerland.

Ann Copestake. 2004. Semantics and generation. In *Proceedings of the 11th International Conference of Head-Driven Phrase Structure Grammar*. CSLI Publications, Stanford.

Simon Dik. 1978. *Functional Grammar*. North-Holland, Amsterdam.

Daniel P. Flickinger. 2000. On building a more efficient grammar by exploiting types. *Natural Language Engineering*, 6(1):15–28.

Daniel Gildea and Daniel Jurafsky. 2002. Automatic labelling of semantic roles. *Computational Linguistics*, 28(3):245–88.

Ben Hayes. 2001. Constructing a semantic sense hierarchy from dictionary definitions. Master's thesis, University of Cambridge.

Kazuko Hiramatsu, William Snyder, Thomas Roeper, Stephanie Storrs, and Mathew Saccomon. 2000. On musical hand chairs and linguistic swing. In *Proceedings of the 24th Boston University Conference on Language Development*, Somerville, USA.

Ebba Hjort and Kjeld Kristensen, editors. 2003. *Den danske ordbog*. Gyldendal.

Mutsumi Imai, Dedre Gentner, and Nobuko Uchida. 1994. Children's theories of word meaning: the role of shape similarity in early acquisition. *Cognitive Development*, 9(1):45–75.

Michael Johnston and Federica Busa. 1999. Qualia structure and the compositional interpretation of compounds. In Evelyne Viegas, editor, *Breadth and depth of semantic lexicons*. Kluwer, Dordrecht.

Barbara Landau, L. Smith, and Susan Jones. 1988. The importance of shape in early lexical meaning. *Cognitive Development*, 3:299–321.

Richard Larson. 1998. Events and modification in nominals. In *Proceedings of Semantics and Linguistic Theories 1998*, Ithaca, USA.

Alessandro Lenci, Federica Busa, Nilda Ruimy, Elisabetta Gola, Monica Monachini, Nicoletta Galzolari, Antonio Zampolli, Emilie Guimier, Gaëlle Recourcé, Lee Humphreys, Ursula von Rekovsky, Antoine Ogonowski, Clare McGauley, Wim Peters, Ivonne Petters, Robert Gaizauskas, and Marta Villegas. 2000. Linguistic specifications. Technical report, SIMPLE Work Package 2.

Alda Mari and Patrick Saint-Dizier. 2004. A conceptual semantics for prepositions denoting instrumentality. In Patrick Saint-Dizier, editor, *Syntax and semantics of prepositions*, pages 345–359. Kluwer, Dordrecht.

Diana McCarthy and John Carroll. 2003. Disambiguating nouns, verbs, and adjectives using automatically acquired selectional preferences. *Computational Linguistics*, 29(4):639–54.

Patrizia Paggio and Bjarne Ørsnes. 1993. Automatic translation of nominal compounds. *Rivista di Linguistica*, 5:129–156.

Terence Parsons. 1991. *Events in the semantics of English*. MIT Press, Cambridge.

Carl J. Pollard and Ivan A. Sag. 1994. *Head-Driven Phrase Structure Grammar*. University of Chicago Press, Chicago.

James Pustejovsky. 1993. Type coercion and lexical selection. In James Pustejovsky, editor, *Semantics and the lexicon*. Kluwer, Dordrecht.

James Pustejovsky. 1995. *The generative lexicon*. MIT Press, Cambridge.

Larissa Samuelson. 2000. Attentional biases in artificial noun learning tasks: generalizations across the structure of already-learned nouns. In *Proceedings of the 22nd Annual Conference of the Cognitive Science Society*, New Jersey, USA.

Anders Søgaard. 2004. A compound matrix. In *Proceedings of the 11th International Conference of Head-Driven Phrase Structure Grammar*. CSLI Publications, Stanford.

Robert van Valin and Randy LaPolla. 1997. *Syntax*. Cambridge University Press, Cambridge.

Carl Vikner and Per Anker Jensen. 2002. A semantic analysis of the english genitive. *Studia Linguistica*, 56:191–226.

Kate Woodford. 2003. *Cambridge Advanced Learners' Dictionary*. Cambridge University Press, Cambridge.