INTERPRETATION AS CONFLICT RESOLUTION

Henriëtte de Swart and Joost Zwarts

Utrecht University - the Netherlands

Abstract

Interpreting words, sentences and discourse is a process of resolving conflicts between the requirements of various general constraints on the correspondence between form and meaning and the interaction between lexicon and context. In this paper the fruitfulness of taking an optimality-theoretic approach to semantic conflict resolution by constraint ranking is illustrated with four case studies from the Dutch research project 'Conflicts in Interpretation' (anaphora resolution, the polysemy of the spatial preposition round, negative concord and the acquisition of indefinites).

1. Background and motivation

Semantic interpretation is not a simple process. When we want to know what a given sentence means, more is needed than just a simple 'adding up' of the meanings of the component words. The words in a sentence can interact and conflict not only with each other, but also with the linguistic and non-linguistic context in which the sentence was uttered. Deictic, anaphoric, and elliptical expressions attune their interpretation to the properties of the context, noun phrases have to be shifted in type to fit a particular argument slot (Partee, 1987), and lexical meanings may need to undergo coercion to match the neighboring words

(Pustejovsky, 1995). Optimality Theory provides a framework to deal with such conflicts in interpretation in a systematic way by means of constraint-ranking (Prince & Smolensky, 1993). In 2002, NWO, the Dutch Organization for Scientific Research, funded a project proposal submitted by Petra Hendriks (Groningen University), Helen de Hoop (University of Nijmegen) and the first author of this paper (Utrecht University) as part of the Cognition Program.[1] The starting point of the project is the notion of conflicts in interpretation and their resolution by constraint-ranking. This paper reports on preliminary results, and sketches the lines of research opening up in this project. We illustrate with four examples: anaphora resolution, the polysemy of the spatial preposition (*round)*, negative concord and the acquisition of indefinites.

2. Optimality Theoretic Semantics

Optimality Theory (OT) is a linguistic meta-theory that arose out of ideas in connectionist theory, or parallel distributed processing, a view on cognition that emerged in the 1980s (cf. Rumelhart et al., 1986). It had been applied to phonology and syntax, before it was first explored as a framework for semantics by Blutner (2000), Hendriks and de Hoop (2001), Zeevat (2000), and de Hoop and de Swart (2000). Smolensky (1996) first identified the connectionist notion of well-formedness in terms of harmony of an activation pattern with the linguistic notion of well-formedness. The connectionist notion of harmony depends on the connections in the network, which create a relation between an input and an output. In OT syntax, the input consists of a meaning, and the output of a form. In OT semantics, the input is a form (utterance), and the output is a meaning. OT syntax is speaker oriented: the speaker who wants to get a certain message across, wants to use the optimal form to express this meaning. OT semantics is hearer oriented: an utterance needs to be understood by the hearer. For any given utterance (form), a number of meaningful candidates need to be evaluated in order to determine the optimal meaning. The decision is determined by a set of constraints, which are ranked in a particular order.

The constraints are soft, that is, they can all be violated. The ranking determines the strength of the constraint, and the violation of a lower ranked constraint is often motivated by the need to satisfy a higher ranked constraint. The constraints are evaluated in parallel, so we can consider different aspects of meaning (e.g., from different modules of the grammar) at the same time. The optimal interpretation that emerges eliminates all other candidates; that is, the winner takes all. This approach to the study of meaning has opened up new lines of thinking about the relation between the lexicon, syntactic structure, intonation, and discourse structure. We illustrate this with the example of anaphora resolution.

3. Anaphora resolution in OT

Hendriks and de Hoop (2001) are concerned with the interpretation of elliptical sentences such as (1a) and (1b):

(1)   a. Who wants the first one?
        b. Most were rejected.

In order to obtain the intended interpretation for quantified, but incomplete or anaphoric expressions, a compositional interpretation based on syntactic structure alone is not possible. We need to take into account lexical knowledge and contextual interpretation.

Hendriks and de Hoop argue that the parallel application of soft constraints from different domains (e.g., contextual, intonational, syntactic...) derives the optimal interpretation.

One very general pragmatic constraint captures the fact that there is a general preference to interpret elements as anaphors, related to the previous discourse. This is formulated as **DOAP** (cf. Williams, 1997):

(2)   **DOAP**: **d**on't **o**verlook **a**naphoric **p**ossibilities.

Opportunities to anaphorize text must be seized.

DOAP is a soft constraint, and can be overruled by other constraints. For instance, the syntactic constraint known as **PRINCIPLE B** is obviously stronger than **DOAP**:

(3)   **PRINCIPLE B**: If two arguments of the same semantic relation are not marked as being identical, interpret them as being dintinct.

If we rank **PRINCIPLE B** higher than **DOAP** (**PRINCB** >> **DOAP**), we can account for the contrast between (4a) and (4b) in terms of different optimal interpretations.

(4)   a. Often when I talk to a doctor, the doctor disagrees with him.
       b. Often when I talk to a doctor, the doctor disagrees with himself.

Interpreting *himself* in (4b) as anaphoric to *the doctor* satisfies both **DOAP** and **PRINCIPLE B**. However, the same anaphoric interpretation for *him* in (4a) would violate **PRINCIPLE B**. Given that **PRINCIPLE B** is ranked higher than **DOAP**, and that we generally prefer a violation of the weaker constraint (**DOAP**) over the stronger constraint (**PRINCIPLE B**), the non-anaphoric reading emerges as the optimal interpretation. This is reflected in the following Tableaux:

Tableau 1: reflexive *himself* (4b)

Form	Meaning	Princ B	DOAP
Often when I ☞ talk to a doctor, the doctor disagrees with himself	A doctor$_1$ the doctor$_1$ himself$_1$		
	A doctor$_1$ the doctor$_2$ himself$_1$		*!
	A doctor$_1$ the doctor$_1$ himself$_2$		*!
	A doctor$_1$ the doctor$_2$ himself$_2$		*!
	A doctor$_1$ the doctor$_2$ himself$_3$		*!*

Tableau 2: pronominal *him*(4a)

Form	Meaning	Princ B	DOAP
Often when I talk to a doctor, the doctor disagrees with him	A doctor$_1$ the doctor$_1$ him$_1$	*!	
☞	A doctor$_1$ the doctor$_2$ him$_1$		*
☞	A doctor$_1$ the doctor$_1$ him$_2$		*
	A doctor$_1$ the doctor$_2$ him$_2$	*!	*
	A doctor$_1$ the doctor$_2$ him$_3$		**!

Each Tableau gives a partial representation of the given input (the form), the set of potential outputs (meanings), and the relevant constraints (**Principle B** and **DOAP**). The strength of the constraints is reflected in the left-right order, so **Principle B** outranks **DOAP** (**PrincB** >> **DOAP**). The indices on the NPs indicate the possible interpretations of the sentence. A fully anaphoric interpretation bears the same index for *a doctor, the doctor,* and the anaphoric expression *him* or *himself*. Obviously, a fully anaphoric interpretation incurs no violation of **DOAP**. All candidates besides the first one violate **DOAP** to a greater or a lesser extent. This is indicated with an asterisk (*). Note that the three middle candidates each incur one violation of **DOAP**, whereas the last candidate in each Tableau incurs two violations of **DOAP**. This reflects the observation that, as far as **DOAP** is concerned, a partly anaphoric interpretation is to be preferred over no anaphoric interpretation at all. The best candidate in Tableau 1 is the candidate that does not violate either **Principle B** or **DOAP**, that is, the fully anaphoric meaning. The optimal candidate is marked as optimal (F). The exclamation marks (!) added to the asterisks in the column for **DOAP** indicate that the violation is fatal, and imply that the candidate is suboptimal. Tableau 2 indicates that violations cannot always be avoided, because the constraints are potentially conflicting. The fact that the sec-

ond and the third candidate are preferred over the first interpretation confirms that PRINCIPLE B is indeed stronger than DOAP. However, we do not accept more violations than necessary, so the last candidate is dispreferred. Note that the same violations which result in the optimal candidates in Tableau 2 were marked as fatal in Tableau 1. This indicates that no violation is fatal in itself, but the Tableau as a whole determines which candidate emerges as optimal. This illustrates the notion of parallel evaluation of constraints.

Obviously, the observation that anaphoric interpretations are preferred does not always answer the question of the antecedent of an anaphoric expression. Especially in the context of a discourse, more than one linguistic antecedent might be available, and other principles come into play to determine which one is the appropriate antecedent. Bouma (2003), Hendriks (2004), de Hoop (2001, 2003), and ongoing research by Gerlof Bouma and Petra Hendriks shows that properties ranging from morphological information (gender: *he/she*, number: *he/they*, case: *he/him*), syntactic structure (subject/object asymmetries, coordination versus subordination), intonation (stress) and discourse structure (distance, topichood) come into play in the process of anaphora resolution. Given the notion of parallel evaluation, it is possible to let all these principles interact in an OT interpretation procedure. This leads to a cross-modular view of semantics.

Following standard ideas about the relation between form and meaning, it might be thought that syntactic principles are generally stronger than pragmatic principles, and that contextual information comes in as a last resort. For instance, PRINCIPLE B is ranked higher than DOAP in Tableaux 1 and 2. If such a view were correct, this would weaken the necessity for a cross-modular approach to semantics. However, it can be shown that syntax does not always win. Consider the contrast between examples (5a) and (5b) (from Hendriks & de Hoop, 2001):

(5)   a. Ten students attended the meeting. Three spoke.
        b. Ten students attended the meeting. Twelve spoke.

In (5a), the preferred domain of quantification for the determiner *three* in the second sentence is the set of students that attended the meeting. This is the intersection of the two argument sets of the first determiner. When we look at the formal properties of determiner denotations, this cannot be a coincidence. Natural language determiners are typically conservative or left-leaning:

(6)   Conservativity: Det(A,B) $\leftrightarrow$ Det(A,A$\cap$B).

Conservativity is rooted in syntactic structure: the set A is typically provided by the N′ that forms a constituent with the determiner. That is, in order to determine the truth value of a quantificational statement, we only need to be concerned with the set that the noun refers to (A), and the intersection of the sets denoted by the noun and the predicate (A$\cap$B). If we then take A$\cap$B to be the domain of quantification of the next determiner, we satisfy DOAP, by means of a natural case of topic reduction. This can be captured in terms of a constraint of **Forward Directionality** (van Kuppevelt, 1996):

(7)   **Forward Directionality**: The topic range induced by the domain of quantification of a determiner (set A) is reduced to the topic range induced by the intersection of the two argument sets of this determiner (A$\cap$B).

Although **Forward Directionality** is well motivated by the syntax of quantificational structures and the property of conservativity of natural language determiners, it is overruled in examples like (5b). It is easy to see that an interpretation in terms of forward directionality would lead to an inconsistent interpretation of (5b), because *twelve* cannot take as its domain of quantification a set that contains only ten individuals. This shows that the constraint which Hendriks and de Hoop label as **Avoid Contradiction** is ranked higher than **Forward Directionality**:

(8)   AVOID CONTRADICTION >> FORWARD DIRECTIONALITY

Although AVOID CONTRADICTION is a very general pragmatic constraint, it is ranked very high. Note that (5b) favors an interpretation in which *twelve* quantifies over students (even though it doesn't quantify over students who attended the meeting). This indicates that DOAP is respected.

Given the emphasis we placed on cross-modularity, it might be thought that OT approaches lend themselves very well for questions of meaning that involve the interaction of semantic and pragmatic aspects of interpretation, but are less suitable for hardcore semantic questions. This would leave OT analyses at the edge of the field of semantics. In order to avoid such a misunderstanding, we discuss an example from lexical semantics in which the notion of conflicts in interpretation plays a central role. Section 3 treats the issue of polysemy in spatial prepositions from an OT perspective.

4. Polysemy and context

In his well-known treatment of *over*, Lakoff (1987) shows that polysemous spatial prepositions involve networks of related meanings. The examples in (9) illustrate this for the meanings of *round* (cf. Hawkins, 1984; Schulze, 1991, 1993; Taylor, 1995; Lindstromberg, 1998):

(9)   a. The postman ran round the block.
          b. The burglar drove round the barrier.
          c. The steeplechaser ran round the corner.
          d. The captain sailed round the lake
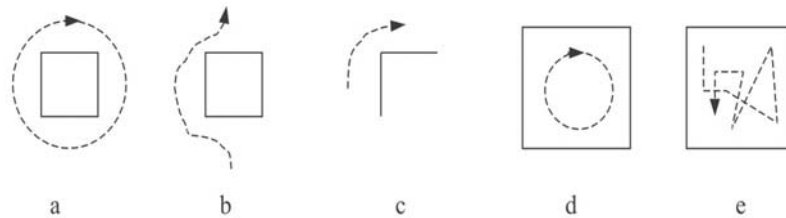   e. The tourist drove round the city center.

Figure 1: Different paths for round

Round describes a full circle in (9a, d), but only a half circle in (9b), and a quarter-circle in (9c). The block defines the central point of the circle in (9a), but the lake provides the outer border of the circle in (9d). In (9e) the city center provides the outer border, and the driving involves a criss-cross movement, rather than a circular one. The question arises how the context-dependent meaning of *round* illustrated in (9) can be accounted for in a theory that respects the principle of compositionality of meaning. The principle of compositionality of meaning says that the meaning of a complex whole is built up of the meaning of its parts and the way they are put together. Zwarts (2003a) argues that the interpretation of *round* in any given context requires the interaction of lexical semantics (involving prototypes in cognitive grammar), model-theoretic semantics (vector space semantics, Zwarts & Winter, 2000), and pragmatics (world knowledge). Consequently, we need a cross-modular approach in which we can assign weights to the semantic contribution of different parts, and determine the optimal meaning by the interaction of semantic and pragmatic constraints. There are different ways we can go about this kind of problem. We can choose an underspecification account, and fill in the contextual properties of the core meaning as we go along (cf. Blutner, 1998, 2000), or we can start with the strongest, prototypical meaning, and weaken it as necessary in the context. Zwarts (2003a) adopts the second line of explanation.

Zwarts suggests that we can organize the conceptual structure referred to by cognitive linguistics into formal semantics by showing

that the meanings of a spatial preposition like *round* involve a cluster of properties that can be described in terms of vector space semantics. He takes the core or prototypical meaning of *round* to correspond to a circle, a circular shape (in two- or three-dimensional space) or a circular movement (9a). This prototypical meaning is modeled in terms of a path, that is, a sequence of vectors located with their starting point in one common origin. The origin is determined by the reference object of the preposition (9a-c), a central point in that reference object (9d), or by an implicitly given reference point. A path is used to represent not only motion, as in (9), but also extension and rotation, as in (10a,b):

(10)   a. Mary has a necklace round her neck.
          b. John turned the wine glass round in his fingers.

A prototypical *round* path has a vector pointing in every direction in a plane, that is, a two-dimensional vector space. This is called COM-PLETENESS.. Not all complete paths are circles. Spirals and ellipses are complete, but they are not circles. What distinguishes circular paths from spiraling and elliptical paths is that all the vectors of a circular path are of the same length. This is called CONSTANCY. Figure 2 illustrates that only perfectly circular paths have both COMPLETENESS and CONSTANCY:
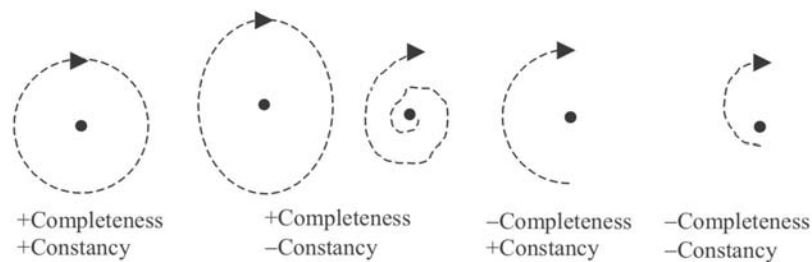

+Completeness   +Completeness   −Completeness   −Completeness
+Constancy   −Constancy   +Constancy   −Constancy

Figure 2: Round and less round

Round shares certain parts of its meaning with other directional prepositions. One of those properties is UNIQUENESS, the property that a

round path describes a circle in the most economical way, without passing any direction twice.

The strongest, prototypical meaning of *round* (9a) can be described by a conjunction of properties, including UNIQUENESS, CONSTANCY and COMPLETENESS.. The weaker, non-prototypical meanings of (9b-e) are characterized by a conjunction of fewer or weaker properties. For instance, the weakening of CONSTANCY allows the path in (11a) to be elliptical. A violation of UNIQUENESS is found in (11b):

(11)   a. The earth goes round the sun.
        b. The mouse keeps running round the computer.
        c. The bridge is damaged, so you will have to go round
           by the lower one.

Weaker versions of COMPLETENESS are INVERSION, which requires there to be two vectors pointing in opposite directions (at least a half-circle), and ORTHOGONALITY, which requires there to be two vectors pointing in perpendicular directions (at least a quarter-circle). INVERSION is the appropriate meaning of *round* in the context of (9b), ORTHOGONALITY emerges in (9c). We find an even weaker meaning in (11c), where *round* gets the meaning of DETOUR, that is, a (slightly) longer path than a straight line.

If we can weaken the properties making up the prototypical meaning of *round*, how do we know which interpretation emerges in a particular context? Zwarts (2003a) extends the Strongest Meaning Hypothesis proposed by Dalrymple et al. (1998) to account for non-prototypical meanings of *round*. The strategy is to prefer the strongest meaning of *round* that is compatible with the context in which it is used. In OT terms, this is captured by means of a combination of two constraints, namely STRENGTH and FIT. The constraint STRENGTH prefers stronger over weaker interpretations (compare Blutner, 2000; Zeevat, 2000). The constraint FIT favors interpretations that do not give rise to a contradictory or unnatural reading (compare Zeevat, 2000, for a similar consistency constraint). It can be seen as a more general version of the con-

straint **Avoid Contradiction** mentioned in section 2 above. **Fit** is ranked over **Strength** (written **Fit >> Strength**), which means that a weaker non-contradictory meaning wins over a stronger contradictory meaning. This is illustrated with the following Tableau for the interpretation of *round the door*.

Tableau 3: The interpretation of *round the door*

Form		Meaning	**Fit**	**Strength**
round the door	☞	Completeness	*!	
		Inversion		*
		Orthogonality		**!
		Detour		**!*

The four possible interpretations of *round the door* are visualized in Figure 3:

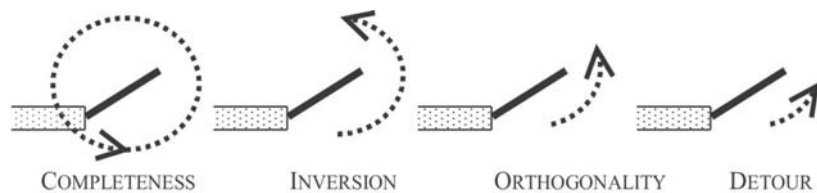COMPLETENESS   INVERSION   ORTHOGONALITY   DETOUR

Figure 3: Four possible interpretations of round the door

The strongest interpretation, in which *round* describes a fully circular path, is excluded because of the conflict in interpretation between this strong, prototypical meaning of *round* and the lexical semantics of *door.*. Doors are not objects that one can normally get fully around upon entering a room. So the Completeness interpretation of *round* is weakened to make it fit the context, and the Inversion reading emerges as the optimal interpretation. Weaker readings involving Orthogonality or Detour are less optimal, because they incur more violations of **Strength** (Completeness being more and more weakened). This can change if more linguistic context is taken into account, as in the sentence 'A man

put his head round the door'. Now the type of path that we choose for *round* also has to fit information about the kind of object that moves or extends along the path, a head in this example. Usually, if someone puts his head round the door, he will remain standing on one side of it. The length and flexibility of human necks do not allow him to move his head all the way to the other side of the door. He will just be able to put his head to the side of the door so that he can see what is outside, or speak with someone standing outside. Taking this pragmatic knowledge into account, we determine that ORTHOGONALITY is the strongest interpretation still fitting the sentence meaning as a whole, because INVERSION violates **FIT** in this context. Interpretation in context, involving everything from lexical semantics and vector space semantics to knowledge of the world is thus crucial to determine the optimal meaning of a form, and thereby resolve the polysemy in ways similar to the way in which we resolved anaphora in section 1 above.

The constraints we have discussed so far are typically very general, possibly even universal, as usual in OT. OT approaches to natural language usually maintain that the constraints are general, but the ranking is specific to the language at hand. Changes in the constraint ranking of phonological and syntactic principles have been used to explain typological differences between languages (Prince and Smolensky, 1993; Grimshaw & Samek-Lodovici, 1998), and have been shown to play a role in diachronic development as well (Jäger, 2002; Zeevat & Jäger, 2002; Rosenbach, 2002; Kusters, 2003; among others). However, with respect to the examples discussed in this section, reranking of constraints does not seem very obvious. It is intuitively not very likely that we will find a language in which, say, **FORWARD DIRECTIONALITY** is ranked higher than **AVOID CONTRADICTION**, and patterns of anaphora resolution are changed accordingly. On the other hand, the idea that meaning can vary from one language to the next and that we need to study semantics from a cross-linguistic point of view has been emerging in the literature (Bach et al., 1995; Chierchia, 1998; among others). Following that line of study, Zwarts (2003b) compares the expression

of 'round' in English and Dutch in a diachronic perspective. However, it is difficult to study these issues from a more general typological perspective. It is easier to study reranking of semantic constraints at the structural level. We will show in section 5 below how changes in ranking can account for variation in the marking and interpretation of negation across languages. But in order to be able to address that issue, we need to say a few words about compositionality and bi-directional optimization first.

5. Compositionality and bi-directional optimization

Compositionality was at issue in the context-dependent meaning of *round*, because we need a systematic way to interpret the complex utterance on the basis of the constituting parts and the way they are put together. Compositionality also plays a role in anaphora resolution. Consider the contrast between (12a) and (12b):

(12)   a. Most ships unload at night.
         b.Most people sleep at night.

Although the two sentences have exactly the same syntactic structure, the preferred interpretation of the quantificational structure is not the same. The dominant interpretation of (12a) is one in which most ships that need to unload do so at night. The preferred interpretation of (12b) says that what most people do at night is to sleep. These meanings are brought out by different stress patterns:

(13)   a Most ships unload AT NIGHT.
         b. Most people SLEEP at night.

According to Generalized Quantifier theory (Barwise & Cooper, 1981), a determiner such as *most* establishes a relation between two sets of individuals. This complex meaning should be the result of the

meaning of the parts and the way they are put together, under the assumption of compositionality of meaning. This implies that we should look at syntactic structure for help in determining which way the constituting parts are put together. The determiner (D) forms a constituent with the noun (N'), called NP (or DP, depending on your preferred syntactic assumptions). Thus it is natural to assume, as Barwise and Cooper do, that N' provides the first argument of the quantifier, and the VP the second argument. However, quantification in (12) is not just about ships or about people, it is about ships that unload and what people do at night. Stress and contextual information play an important role in determining the full argument structure of a quantifier (Partee, 1991, 1995), as illustrated by (13a, b).

However, as Blutner et al. (2003) point out, it is not so obvious how to formalize the influence of context and lexical knowledge on the truth-conditions of quantificational structures, because the different factors may be in conflict with each other: syntactically optimal interpretations may be pragmatically unlikely. According to Blutner et al. (2003), there are different ways of solving the tension between form and meaning in these kinds of examples. One solution might be to do away with the principle of compositionality of meaning altogether. Another solution would be to relate compositionality to the notion of recoverability. Recoverability is usually assumed as a meta-restriction on syntactic analyses. It requires the semantic content of elements that are not pronounced to be recoverable from local context (Pesetsky, 1998; Kuhn, 2001; Buchwald et al. 2002). If recoverability and compositionality are in fact two sides of the same coin, we need to view compositionality problems in the light of bi-directional optimization. In bi-directional OT, the speaker's and the hearer's perspective are taken into account simultaneously, and we evaluate pairs of forms and meanings. Bi-directional OT guarantees a general procedure of optimization from form to meaning and from meaning to form such that a speaker's optimal expression of a meaning and a hearer's optimal interpretation of a form depend on each other in each context in a well-defined way. We will illus-

trate this general idea with the marking and interpretation of negation in natural language.

6. Negation in bi-directional OT

The fact that bi-directional optimization and compositionality hang together is illustrated by another set of observations, this time within the realm of negation. Natural languages generally have expressions for negation and denial, so something that expresses the connective ¬. They also frequently have ways to refer to the negative quantifier ¬∃x. In English, these would be the negation marker *not* and the negative indefinite pronouns *nothing/nobody*. In Italian these would be *non* and *niente/nadie*. In Portuguese, these would be *não* and *nada/ninguém*. If we assume that knowledge of something like first-order logic, or something equivalent to first-order logic is part of general human cognition, we might predict that negation and negative quantifiers behave the same across languages. From empirical research by typologists and theoretical linguists, we know that this is not the case (cf. Jespersen, 1917/1962, 1933/1964; Dahl, 1979; Payne, 1985; Horn, 1989; Ladusaw, 1992, 1996; Bernini & Ramat, 1996; and Haspelmath, 1997, for overviews of the empirical facts). In particular, we know that in many cases, *nothing, niente, nada* … behave alike as negative answers to a question. This is illustrated by the following ad from Dixons, a company that sells cell phones, which appeared in the Dutch papers in the summer of 2003:

(14)   Quanta Costa?   Niets, nada, niente.
        Dixons heeft de zomer in zijn bol. En in zijn winkels. Met drie top-telefoontjes voor niets, noppes, nada, niente. En dat is niet verkeerd, zo vlak voor de vakantie.
        Quanta Costa?   Nothing, *nada, niente*.
        Dixons has summer on the brain. And in its stores. With three top of the line phones for nothing, zip, *nada, niente*. And that's not a bad idea, right before the summer vacation.

The italicized bits in the translation illustrate the parts where the Dutch ad uses Spanish/Portuguese/Italian bits of phrases. *Noppes* is a synonym of *niets* (just somewhat more informal in register, and somewhat more emphatic in meaning). The point of the repetition of words meaning 'nothing' in Dutch and other languages is obviously emphatic: these phones cost nothing at all, they are totally free (in combination with a paid subscription to a particular phone company, of course, but that is in the small print not spelled out here). The point of the example in this paper is that the words, in isolation, mean the same thing. That is, at the lexical level we cannot establish a distinction between the negative indefinite pronouns *niets, noppes, nothing, nada, niente*. As a stand alone response to a question as in (14), they all mean 'nothing'. However, most linguists are aware of the fact that differences do arise when we combine more than one of these expressions in the context of a (single clause) sentence, as witnessed by the following examples:

(15) a. Nobody said nothing.   English $\neg\exists x\neg\exists y$ Say(x,y)
      b. Niemand zei niets.   Dutch $\neg\exists x\neg\exists y$ Say(x,y)
      c. Nadie a dijo   Spanish $\neg\exists x\exists y$
         a nada.   Speak_with(x,y)
      d. Nessuno ha parlata   Italian $\neg\exists x\exists y$ Say(x,y)
         con nessuno
      e. Ninguém disse nada.   Portuguese $\neg\exists x\exists y$ Say(x,y)

The first two languages (English, Dutch) exemplify the phenomenon of double negation, that is, the combination of two negations leads to the expression of double negation. The last three languages exemplify the phenomenon of so-called 'negative concord', that is, the combination of two – or more – negations leads to the expression of single negation. In order to express the single negation reading of sentences (15c-e), languages like English and Dutch use indefinite pronouns (*iets* in 16b) or negative polarity items (*anything* in 16a) for the argument embedded under negation:

(16)   a. Nobody said anything.   English $\neg\exists x\exists y\ Say(x,y)$
        b. Niemand zei iets.   Dutch $\neg\exists x\exists y\ Say(x,y)$

Expressions that participate in negative concord are called 'n-words' (see Corblin et al., 2004 and references therein). De Swart (2004) uses the term 'neg expressions' to generalize over negative quantifiers like English *nobody, nothing,* and n-words like Spanish *nadie,* Italian *nessuno,* Portuguese *ninguém,* and distinguish them from indefinite pronouns like Dutch *iets* 'something', and polarity items like English *anything.*

Negative concord is widespread across the languages of the world (Ladusaw, 1996, Haspelmath 1997). Even though it might be the typological default, it is a curious phenomenon from a semantic perspective, because it raises serious problems for the principle of compositionality. The laws of negation from first-order logic predict that the combination of two negations leads to a double negation reading as in (15a, b). So how can we explain the fact that n-words express negation in isolation, but that a sequence of n-words does not lead to multiple negation readings? The strategy here as before in this paper should be that interpretation needs to take place in context. That is, the observation that negative quantifiers and n-words behave the same way in isolation, but not in the context of a sequence needs to be taken seriously. We will explain this fact here as the result of the distribution of labor between syntax and semantics in a language.

The basic intuitions are the following. Negative concord languages like Romance mark the arguments embedded under negation formally as negative (by means of n-words), but make sure that each neg expression does not necessarily contribute a semantic negation (so a sequence of n-words expresses a single negation, cf. 15c-e). Double negation languages like the Germanic languages necessarily interpret all neg expressions as contributing a negation (so two negative quantifiers lead to double negation, cf 15a,b), but make sure that arguments embedded under negation are not formally marked as negative (so use indefinite pronouns or negative polarity items rather than neg expressions, cf. 16a, b). The fact that double negation and negative con-

cord languages rely on a different balance between formal marking and semantic interpretation, and that each system has to make sacrifices to achieve this balance, suggests that a bi-directional OT analysis (relating meaning to form, and form to meaning) is the most appropriate approach to address these issues.

The starting point of the analysis is the observation that negation is marked, both in form and in meaning (Payne, 1985; Horn 1989; and others). That is, expressions conveying (a) negation are morphologically or syntactically more complex than their positive or affirmative counterparts. And a proposition that does not involve an expression 'flagging' negation in some way or another will be interpreted as affirmative, rather than as negative. This leads de Swart (2004) to posit the constraint *NEG:

(17) ***NEG**
       Avoid Negation

*NEG is an output oriented constraint, which favors candidates that do not mark negation formally, or that do not interpret expressions as negative over others. Thus it qualifies as a markedness constraint in OT. ***NEG** is balanced by two faithfulness constraints, which emphasize that information from the input should be reflected in the output. For (the) OT syntax, this is MaxNeg (18), for (the) OT semantics, this is IntNeg (19):

(18) **MAXNEG**
       Mark the argument of a negative chain
(19) **INTNEG**
       Interpret all Neg expressions in the input (form) as contribut
       ing a negative meaning in the output (meaning)

How can we use these constraints to account for double negation and negative concord? We propose that they rely on two different rankings of these constraints. Negative concord arises under the rank-

ing **MaxNeg** >> ***Neg** >> **IntNeg**. Double negation languages involve the ranking **IntNeg** >> ***Neg** >> **MaxNeg**. This is illustrated by Tableau 4a and 4b for negative concord languages, and Tableau 5a and 5b for double negation languages, which exemplify the bi-directional optimization for a sentence involving the binding of two variables:

Tableau 4a (generation of NC)

Meaning		Form	MaxNeg	*Neg	IntNeg
$\neg\exists x_1 \exists x_2$		neg + indef	*	*	
	☞	neg + neg		**	

Tableau 4b (interpretation of NC)

Form		Meaning	MaxNeg	*Neg	IntNeg
neg + neg		$\neg\exists x_1 \neg\exists x_2$		**	
	☞	$\neg\exists x_1 \exists x_2$		*	*

Tableau 5a (generation of DN)

Meaning		Form	IntNeg	*Neg	MaxNeg
$\neg\exists x_1 \exists x_2$	☞	neg + indef		*	*
		neg + neg		**	

Tableau 5b (interpretation of DN)

Form		Meaning	IntNeg	*Neg	MaxNeg
neg + neg	☞	$\neg\exists x_1 \neg\exists x_2$		**	
		$\neg\exists x_1 \exists x_2$	*		

Tableau 4a shows that the combination of two neg expressions is the optimal form for the meaning $\neg\exists x_1 \exists x_2$. The single negation reading comes out as the optimal meaning of the combination of two neg expressions in Tableau 4b. Tableau 5a illustrates that double negation languages generate indefinites within the scope of negation as the op-

timal form. If we combine two neg expressions anyway, we end up with a double negation reading, as illustrated in Tableau 5b. Thus the two rankings account for our basic intuitions about negative concord and double negation as two ways of bi-directional optimization.

• Negative Concord: If you mark arguments of a negative chain formally (MAXNEG >> *NEG in production), then make sure you do not interpret each Neg expression as contributing a semantic negation (*NEG >> INTNEG in interpretation).

• Double Negation: If you interpret each Neg expression as contributing a semantic negation (INTNEG >> *NEG in interpretation), then make sure you do not mark arguments of a negative chain formally (*NEG >> MAXNEG in production).

The example of marking and interpretation of negation makes it clear that compositionality problems may be motivated by the syntax, and that languages may differ in the way they balance out syntax and semantics. A procedure of bi-directional optimization leads to new insights for questions that so clearly concern the interface between form and meaning. An important question that arises in this context is the question of language acquisition. How do children learn to balance out the syntax and semantics of their mother tongue? Section 6 will show that bi-directional optimization is not an easy skill to acquire.

7. OT Semantics, bidirectionality and language acquisition

Smolensky (1996) and Tesar and Smolensky (1998) show that the OT approach also sheds new light on questions of language acquisition. They argue that children start out with a system in which markedness constraints are ranked above faithfulness constraints. This explains why children generally understand much more than they can produce. Reranking of constraints is then part and parcel of the acquisition process. Ongoing research by Irene Krämer is testing this hy-

pothesis for semantic aspects of acquisition by studying the interpretation of quantifiers like *many*, and the interpretation of indefinites and pronouns in the context of a story. Furthermore, de Hoop and Krämer (2004) show that bi-directionality also plays a role in language acquisition. It is well known (Lidz & Musolino, 2002) that there is an asymmetry between the children's interpretation of indefinites in subject and in object position. Indefinite subjects are by default interpreted as *referential* (type *e,* according to van der Does and de Hoop 1998), whereas indefinite objects are by default interpreted as *non-referential* (type *<e,t>* according to van der Does and de Hoop, ibid). The two readings differ in the anaphoric element they may combine with. When the object *a guy* is interpreted non-referentially, it may be followed by the indefinite anaphor *one* in (20). If the same object is interpreted referentially, it may be followed by the referential pronoun *him* in (21):

(20)   Donald saw a guy, and Ronald saw one too. [non-referential]

(21)   Donald saw a guy, and Ronald saw him too. [referential]

The well-formedness of (21) illustrates that referential readings of indefinite objects are available in the adult language. Indeed, in Germanic languages, scrambling of the object typically brings out the referential interpretation as the only available reading. Compare the following contrast:

(21)   Je mag twee keer een potje omdraaien. [Dutch]
        You may two time a pot around-turn.
        'You may turn around a pot twice.'

(22)   Je mag een potje twee keer omdraaien.
        You may a pot two time around-turn.
        'You may turn around a pot twice.'

The position of the indefinite *een potje* to the right of the adverbial in (21) is the default, unscrambled position of the object. The position to the left of the adverbial in (22) is the scrambled position of the indefinite object. Krämer (2000) confirms that adults usually assign the unscrambled object (21) a non-referential reading, whereas the scrambled object (22) always gets a referential interpretation. Most children under 7, however, interpret the scrambled objects non-referentially as well. Similar observations have been made with respect to English, Kannada, and other languages (cf. de Hoop & Krämer, 2004 for references).

One potential explanation for these findings might be that children have a general preference for interpreting indefinite noun phrases non-referentially. However, this cannot be true, in view of the fact that children are perfectly capable of obtaining a referential interpretation for indefinite subjects in sentences like (23):

(23)   Een meisje gleed twee keer uit.
        A girl slipped two times out[particle].
        'A girl slipped twice.'

In sum, children are adult-like in their interpretation of referential indefinite subjects, and in their interpretation of non-referential indefinite objects. They differ from adults when they have to interpret non-referential indefinite subjects, and when they have to interpret referential indefinite objects. The explanation de Hoop and Krämer offer for these observations is that the preferred (unmarked) reading for indefinite objects in default (i.e. unscrambled) position is the non-referential interpretation, whereas the preferred (unmarked) reading for indefinite subjects in default (i.e. Spec-IP) position is the referential interpretation. In existential *there* sentences we find non-referential readings of indefinites, but there the subject is in Spec-VP position. Children start out by learning to associate unmarked forms and unmarked meanings, and the combination of marked forms with marked meanings is not acquired until later. They work this out in a bi-directional optimality theoretic analysis of the subject-object asymmetry. They use two constraints on form, and two constraints on meaning in their analysis:

M1: Subjects outrank objects in referentiality; i.e., subjects get a referential interpretation, while objects get a non-referential interpretation.
M2: Indefinite noun phrases get a non-referential interpretation.
F1: Indefinite objects do not scramble.
F2: Subjects are in standard subject position, referred to as [Spec, IP].

Putting these four constraints together gives the unmarked meanings of indefinite subjects and objects from an OT semantic point of view, and the unmarked forms from an OT syntactic point of view. For the combination of marked forms and marked meanings, de Hoop and Krämer appeal to the bidirectional notion of *superoptimality*. According to Blutner (2000) a form-meaning pair <f,m> is superoptimal if and only if there is no other super-optimal pair <f',m> such that <f',m> is more harmonic than <f,m>, and there is no other super-optimal pair <f,m'> such that <f,m'> is more harmonic than <f,m>. Both unmarked form-meaning pairs <f,m> and marked form-meaning pairs <f',m'> come out as *superoptimal* in this set-up. This is reflected in the following Tableau, where the super-optimal pairs are indicated with the symbol ✌:

Tableau 6 (indefinite objects in bidirectional OT)

input: [f,m] indefinite object f1: unscrambled; f2: scrambled m1: non-referential <e,t>; m2: referential <e>		M1	M2	F1
[-scrambling, <e,t>]	✌			
[-scrambling, e]		*	*	
[+scrambling, <e,t>]				*
[+scrambling, e]	✌	*	*	*

Tableau 7 (indefinite subjects in bidirectional OT)

input: [f,m] indefinite subject f1: standard (Spec-IP); f2: embedded (Spec-VP) m1: referential <e>; m2: non-referential <e,t>		M1	M2	F2
[Spec-IP, e]	☞		*	
[Spec-IP, <e,t>]		*		
[Spec-VP, e]			*	*
[Spec-VP, <e,t>]	☞	*		*

Tableau 6 shows that the indefinite object that combines a referential meaning with a scrambled word order violates all three relevant constraints. Still, it represents a superoptimal pair, for there is no other superoptimal pair available that has either a more harmonic form or a more harmonic meaning. Similarly, Tableau 7 shows that one superoptimal pair links the unmarked meaning to the unmarked position [Spec-IP, e], while the other super-optimal pair links the marked meaning to the marked position [Spec-VP, <e,t>].

The bidirectional OT analysis straightforwardly explains the adult pattern of the interpretation of both indefinite subjects and objects. Adults are able to evaluate form-meaning pairs. That means that they not only can find the optimal form for a certain meaning or the optimal meaning of a certain form, but they are also capable of determining as a superoptimal pair the combination of a form that is sub-optimal from a unidirectional syntactic perspective, and a meaning that is sub-optimal from a unidirectional semantic perspective. The central claim de Hoop and Krämer are making is that children cannot evaluate form-meaning pairs yet. In interpreting indefinites, they optimize unidirectionally, and choose the unmarked, i.e., non-referential meaning for the unmarked (unscrambled) objects as well as for the marked (scrambled) objects. Similarly, they derive the unmarked (referential) reading for subjects in standard and embedded position. In order to obtain the right interpretation for the indefinite in a marked position, the child must learn to apply the process of optimization bidirectionally.

The child needs to learn to reason as follows: I can find the optimal interpretation for this form, but I notice that the form is sub-optimal; the speaker would have used the optimal form for the unmarked meaning, therefore I must choose the sub-optimal meaning for this sub-optimal form, which will give me another (marked) superoptimal form-meaning pair. Before the 4-year-old child can become a competent, adult-like hearer of her language, she must acquire the full process of optimization of interpretation, which includes the speaker's perspective of optimization in a bidirectional approach.

8. Moving on...

As we tried to show in this paper, Optimality Theory opens up a new way of thinking about semantics, and raises a whole new set of research questions. The examples discussed in this paper highlight the interaction of constraints from different domains (cross-modularity) in the process of anaphora resolution, the role of context in the interpretation of polysemous expressions like *round*, the need for bi-directional optimization in the case of compositionality questions raised by negation, and the role of OT semantics and bidirectionality in language acquisition. In all cases, we emphasized the need to interpret expressions in context. This can be the sentential context, the discourse context, or more broadly, the context of general cognition, involving various stages of acquisition. Ongoing research by several members of the project group focuses on the embedding of the results obtained so far in a more general, cognitive framework. Ongoing research by Gerlof Bouma and Petra Hendriks studies the relation between syntactic structure (coordination vs. subordination) and discourse structure in the resolution of anaphora (pronouns, ellipsis). Helen de Hoop, Joost Zwarts and Henriëtte de Swart continue their research on the ranking of semantic and syntax-semantics interface constraints in their study of cross-linguistic variation in meaning. Ongoing research by Irene Krämer and Petra Hendriks aims at an integration of the learning of language

and learning in other cognitive domains. For instance, children need to learn to give priority to linguistic and discourse information over extra-linguistic (general and contextual) information. If we can model these issues in terms of a ranking of violable constraints, we can hopefully find new ways of connecting linguistics to other domains of cognitive science.

Notes

1. We thank our collaborators in the research project Gerlof Bouma, Petra Hendriks , Helen de Hoop, and Irene Krämer for fruitful discussion and help with the final version. We thank NWO (grant 051-02-072 for the project "Conflicts in Interpretation") for their financial support in the context of the Cognition Program.

2. Any other potential ranking of the three constraints is shown to be unstable by de Swart (2004).

References

Bach, E., et al. (1995). *Quantification in natural languages.* Dordrecht: Kluwer Academic Press.

Barwise, J., & R. Cooper (1981). Generalized quantifiers and natural language. *Linguistics and Philosophy, 4*, 159-219.

Bernini, G. & Ramat, P. (1996). *Negative sentences in the languages of Europe*. Berlin: Mouton de Gruyter.

Blutner, R. (1998). Lexical pragmatics. *Journal of Semantics, 15*, 115-162.

Blutner, R. (2000). Some aspects of optimality in natural language interpretation, *Journal of Semantics, 17*, 189-216.

Blutner, R., Hendriks, P., & de Hoop, H. (2003). A new hypothesis on compositionality, *Proceedings of ICCS 2003.* Sidney.

Bouma, G. (2003). Doing Dutch pronoun resolution automatically in Optimality Theory. *Proceedings of the EACL 2003 workshop on the computational treatment of anaphora*. Budapest.

Buchwald, A., Schwartz, O., Seidl, A., & Smolensky, P. (2002). Recoverability Optimality Theory: Discourse anaphora in a bidirectional framework. *Proceedings of the sixth workshop on the semantics and pragmatics of dialogue (EDILOG 2002)*. 1604-1610.

Chierchia, G. (1998). Plurality of mass nouns and the notion of 'semantic parameter'. In S. Rothstein (Ed.), *Events and grammar*. Dordrecht: Kluwer academic press.

Corblin, F., Déprez, V., de Swart, H., & Tovena, L. (in press). Negative concord. In F. Corblin & H. de Swart (Eds.), *Handbook of French Semantics*. Stanford: CSLI Press.

Dahl, Ö. (1979). Typology of sentence negation. *Linguistics, 17*, 79-106.

Dalrymple, M., Kanazawa, M., Kim Y., Mchombo, S., & Peters, S. (1998). Reciprocal expressions and the concept of reciprocity, *Linguistics and Philosophy, 21*, 159-210.

van der Does, J., & de Hoop, H. (1998). Type shifting and scrambled definites. *Journal of semantics, 15*, 393 - 416.

Grimshaw, J., & Samek-Lodovici, V. (1998). Optimal subjects and subject universals. In P. Barbarosa, D. Fox, P. Hagstrom, M. McGinnis, & D. Pesetsky (Eds.), *Is the Best Good Enough? Papers from the Workshop on Optimality in Syntax* (pp. 193-219). Cambridge: MIT Press.

Haspelmath, M. (1997). *Indefinite pronouns*. Oxford: Clarendon Press.

Hawkins, B. (1984). *The semantics of English spatial prepositions*. Unpublished doctoral dissertation, University of California, San Diego.

Hendriks, P. (in press). Coherence relations, ellipsis and contrastive topics. *Journal of Semantics*.

Hendriks, P., & Hoop, H. de (2001). Optimality theoretic semantics. *Linguistics and Philosophy, 24*, 1-32.

Hoop, H. de (2001). Complementary preference overruled: stressed pronouns in discourse. *Proceedings of the 13th Amsterdam Colloquium,* Amsterdam: ILLC, 108-113.

Hoop, H. de (2003). Scrambling in Dutch: optionality and optimality. In S. Karimi (Ed.), *Word order and scrambling* (pp. 201-216). Oxford: Blackwell.

Hoop, H. de, & Krämer, I. (2004). *Children's optimal interpretations of indefinite subjects and objects*. Radboud University, Nijmegen, the Netherlands. (Manuscript submitted for publication).

Hoop, H. de, & Swart, H. de (2000). Temporal adjunct clauses in optimality theory. *Italian Journal of Linguistics, 12*, 107-127.

Horn, L. (1989). *A natural history of negation*. Chicago: University of Chicago Press. Jäger, G. (2004). Learning constraint hierarchies. The bi-directional gradual learning algorithm. In: R. Blutner, & H. Zeevat (Eds.), *Optimality Theory and Pragmatics* (pp. 251-287). Hampshire, England: Palgrave McMillan.

Jespersen, O. (1962). Negation in English and other languages. In *Selected writings of Otto Jespersen* (pp. 3-151). London: George Allen and Unwin. (Reprinted from O. Jespersen, (1917). *Negation in English and other languages.* Copenhagen: A.F. Høst)

Jespersen, O. (1964). *Essentials of English grammar*. University of Alabama Press. (Original work published 1933)

Krämer, I. (2000). *Interpreting indefinites: an experimental study of children's language comprehension*. Unpublished doctoral dissertation, Utrecht University, the Netherlands.

van Kuppevelt, J. (1996). Directionality in discourse: Prominence differences in subordination relations. *Journal of Semantics, 13*, 363-395.

Kusters, W. (2003). *Linguistic complexity: the influence of social change on verbal inflection.* Doctoral dissertation, University of Leiden, the Netherlands.

Kuhn, J. (2001). *Formal and computational aspects of optimality-theoretic syntax.* Doctoral dissertation, University of Stuttgart, Germany.

Ladusaw, W. (1992). Expressing negation. *Proceedings of SALT* 2 (pp. 237-259 Columbus: Ohio State University.

Ladusaw, W. (1996). Negation and polarity items. In S. Lappin (Ed.), *The handbook of contemporary semantic theory.* Oxford: Blackwell.

Lakoff, G. (1987). *Woman, fire and dangerous things.* Chicago: Chicago University Press.

Lidz, J., & Musolino, J. (2002). Children's command of quantification. *Cognition, 84,* 113-154.

Lindstromberg, S. (1998). *English prepositions explained.* Amsterdam: John Benjamins Publishing Company.

Partee, B. (1987). Noun phrase interpretation and type shifting principles. In J. Groenendijk, D. de Jong, & M. Stokhof (Eds.), *Studies in Discourse Representation Theories and the Theory of Generalized Quantifiers* (pp. 115-144). Dordrecht: Foris. Partee, B. (1991). Topic, focus and quantification. *Proceedings of SALT I.* (pp. 159-187). Ithaca, NY. Cornell University.

Partee, B. (1995). Quantificational structures and compositionality. In E. Bach, E. Jelinek, A. Kratzer, & B.H. Partee (Eds.), *Quantification in Natural Languages.* Kluwer: Dordrecht.

Payne, J. (1985). Negation. In T. Shopen (Ed.), *Language typology and syntactic description I: clause structure.* Cambridge: Cambridge University Press.

Pesetsky, D. (1998). Some optimality principles of sentence pronunciation. In P. Barbarosa, D. Fox, P. Hagstrom, M. McGinnis, & D. Pesetsky (Eds.), *Is the Best Good Enough? Papers from the Workshop on Optimality in Syntax* (pp. 337-384). Cambridge: MIT Press.

Prince, A., & Smolensky, P. (1993). *Optimality Theory: Constraint Interaction in Generative Grammar* (RuCCS Tech. Rep. No. 2). Piscataway, NJ: Rutgers Center for Cognitive Science, Rutgers University, & Boulder, CO: Department of Computer Science, University of Colorado.

Pustejovsky, J. (1995). *The Generative Lexicon.* Cambridge, MA: MIT Press.

Rosenbach, A. (2002). *Genitive variation in English: conceptual factors in synchronic and diachronic studies.* Berlin: Mouton de Gruyter.

Rumelhart, D., McClelland, J., & PDP Research Group (1986). *Parallel Distributed Processing: Explorations in the Microstructure of Cognition.* Cambridge, MA: MIT Press.

Schulze, R. (1991). Getting round to *(a)round*: towards a description and analysis of a spatial predicate In G. Rauh (Ed.), *Approaches to preposition.* (pp. 251-274). Tübingen: Gunter Narr Verlag.

Schulze, R. (1993). The meaning of to *(a)round*: a study of an English preposition. In R. A. Geiger, & B. Rudzka-Ostyn (Eds.), *Conceptualizations and mental processing in language* (pp. 399-431). Berlin: Mouton de Gruyter.

Smolensky, P. (1996). Constituent structure and explanation in an integrated connectionist/symbolic architecture. In C. Macdonald & G. Macdonald (Eds.), *Connectionism. Debates on pschychological explanation.* Oxford: Blackwell.

Smolensky, P. (1996). On the comprehension/production dilemma in child language. *Linguistic Inquiry, 27*: 720-731.

Swart, H. de (in press). Marking and interpretation of negation: a bi-directional OT approach. In R. Zanuttini, H. Campos, E. Herburger, & P. Portner (Eds.), *Negation, Tense and Clausal Architecture: Cross-linguistic Investigations.* Georgetown University Press.

Taylor, J. (1995). *Linguistic categorization: prototypes in linguistic theory.* Oxford: Clarendon Press.

Tesar, B., & Smolensky, P. (1998). Learnability in optimality theory. *Linguistic Inquiry, 29*, 229-268.

Williams, E. (1997). Blocking and anaphora. *Linguistic Inquiry,* 28, 577-628.

Zeevat, H. (2000). The asymmetry of Optimality Theoretic Syntax and Semantics. *Journal of Semantics, 17*, 243-262.

Zeevat, H., & Jäger, G. (2002). A reinterpretation of syntactic alignment. *Proceedings of the 4th international Tbilisi Symposium on language, logic and computation.* Amsterdam: ILLC.

Zwarts, J. (2003a). Paths round a prototype. In P. Saint-Dizier (Ed.), *ACL-SIGSEM* workshop: The Linguistic Dimensions of Prepositions and their Use in Computational *Formalisms and Applications (pp.* 228-238). Toulouse: IRIT.

Zwarts, J. (2003b). Lexical competition: 'round' in English and Dutch. In P. Dekker & R. van Rooij (Eds.), *Proceedings of the Fourteenth Amsterdam Colloquium* (pp. 229-234). University of Amsterdam.

Zwarts, J., & Winter, Y. (2000). Vector space semantics: a model theoretic analysis of locative prepositions. *Journal of logic, language and information,* 9: 169-211.