Bidirectional Grammar and Bidirectional Optimization

Reinhard Blutner & Anatoli Strigin

Abstract

The human language faculty is a bidirectional system, i.e. it can be used by processes of approximately equal computational complexity to understand and to generate utterances of a language. We assume the general framework of optimality theory and treat the language faculty as a constraint-based system where the very same constraints are uses both in comprehension and in generation. In the simplest case comprehension and generation can be modelled by unidirectional optimization: finding an optimal interpretations for a given speech input in the case of comprehension; producing an optimal expression for a given message in case of generation. In the simplest case, the speaker and the listener roles are strictly separated. However, there are linguistic observations which indicate that the listener's and the speaker's perspectives are integrated to some extent. Bidirectional optimization is an explicit proposal for doing the integration.

In this article we propose a general architecture of the language faculty and discuss the precise extent to which speakers are listener-oriented and/or listeners are speaker-oriented. Interestingly, this extent does not seem to vary with regard to the different subsystems considered: the sensorimotor system, the system of grammar proper and the conceptual-intentional system (pragmatics). Though the experimental evidence is not very strong at the moment it seems in online processing the speaker takes the hearer into account but not *vice versa*. Besides the online (actual processing) view of bidirection we discuss bidirectional optimization as an offline phenomenon taking place during language acquisition, and giving raise to fossilization phenomena.

1 Introduction

In the computational linguistics literature (e.g. Appelt, 1989) a grammar is called *bidirectional* if it can be used by processes of approximately equal computational complexity to parse and generate sentences of a language. The complexity clause ensures that humans can communicate timely, i.e. the speaker's speed of generation is just right for comfortably comprehending him. Because computational linguists are concerned with the *meanings* of sentences that are processed, a bidirectional grammar must specify a correspondence between sentences and meaning representations, and this correspondence must be represented in a manner that allows one to be computed from the other.

Appelt (1989) stresses that to be of use both for production and comprehension, a bidirectional grammar has to be represented declaratively. If any information is represented procedurally, it must of necessity be represented differently for parsing and generation processes, resulting in an asymmetry between the two. Following Appelt, a declarative grammar could based on the (associative and commutative) unification of feature structures such as the PATR II formalism (Shieber, 1986) or on some more modern forms of constraint-based and inherently nondirectional grammars (for instance see Bresnan, 2000; Jackendoff, 2002). Presently, optimality theory (OT) is the dominant framework for realizing such bidirectional grammars (cf. Prince & Smolensky, 1993/2004; Smolensky & Legendre, 2006).

The simplest way to realize comprehension and generation strategies within OT is by unidirectional optimization: speakers try to find the optimal form to express a given meaning;

listeners try to find the optimal interpretation for a given form. In the context of computational linguistics the applicability of expressive optimization (speaker's view) has been discussed by Kuhn (2001, 2003). Optimal interpretation (listener's view) has been discussed by Fanselow, Schlesewsky, Cavar, & Kliegl (1999), *inter alia*, and it as been demonstrated that this view can be used to construct cognitively realistic models of online, incremental interpretation.

Bidirectional optimization goes beyond the unidirectional optimization account by assuming that the speaker's and the hearer's perspective are integrated into a simultaneous optimization procedure. The motivation for assuming bidirectional optimization comes from the Zipfean idea that the human language faculty is subject to two simultaneous pressures: it must produce well-formed linguistic expressions as efficiently as possible, but it also must produce utterances that can be easily comprehended (Blutner, 1998; Horn, 1984; Zipf, 1949). Often these two pressures are in conflict and bidirectional optimization has to offer a resolution of this conflict. There are two principled ways of how and when the conflict can be resolved (cf. Blutner, 2007b): the *online processing view* suggests that this conflict resolution takes place online during actual utterance interpretation/generation; the *fossilization view* suggests that the conflict is resolved during certain stages of language acquisition. In terms of OT the latter view is expressed as a mechanism of constraint adaptation, i.e. the weighting/ranking of the constraints is changed under the influence of the two diametric Zipfean forces.

To put it in other words, we see two different ways of interpreting bidirection in OT. First, there is the assumption of bidirectional optimization as a psychologically realistic online mechanism. According to this online/synchronic view, speakers (hearers) optimize bidirectionally and take into account hearers (speakers) when selecting (interpreting) a natural language expression. This contrasts with the diachronic view of bidirection according to which bidirectional optimization takes place during language acquisition and leads to *fossilizing* the optimal form-interpretation pairs.[1]

In this article we propose a general architecture of the human language faculty which integrates the grammar component, the conceptual-intentional system (usually called pragmatics) and the sensorimotor system. We will consider to what extent the listener's and the speaker's perspectives are integrated in online processing with regard to these three systems. Furthermore, the emerging interplay between fossilization and bidirectional online processing will be discussed in terms of cognitive economy and cognitive resources.

This article is organized as follows. In section 2 we discuss the proposed general architecture of the human language faculty. Three different notions of bidirectionality are introduced in section 3, together with the general idea of fossilization in OT. Section 4 considres empirical evidence for bidirectional optimization in the domain of sensorimotorics. In section 5 the system of bidirectional grammar is considered. Section 6, finally discusses bidirection and fossilization in the domain of pragmatics. Section 7 draws some tentative conclusions.

2 The architecture of the human language faculty

[1] To make things even more complicated, there is a third possibility to realize conversational implicatures. This third possibility requires real 'mind reading' capacities (conscious reflections) and proceeds offline. Of course, the important question is how to discriminate between such offline implicatures that are not fossilized and their fossilized counterparts. As far we can see none of the existing pragmatic theories has an interesting answer to this long-standing and intriguing question (cf. Cole, 1975). We will ignore the third possibility since we feel the two other options cover what happens under most normal circumstances.

Intuitively, a grammar is a bidirectional system that relates meanings to forms and forms to meanings. Because the grammar is embedded in the cognitive system, we must not only look at the grammar itself but also at the way it interacts with the other cognitive systems. Figure 1 illustrates the basic design.

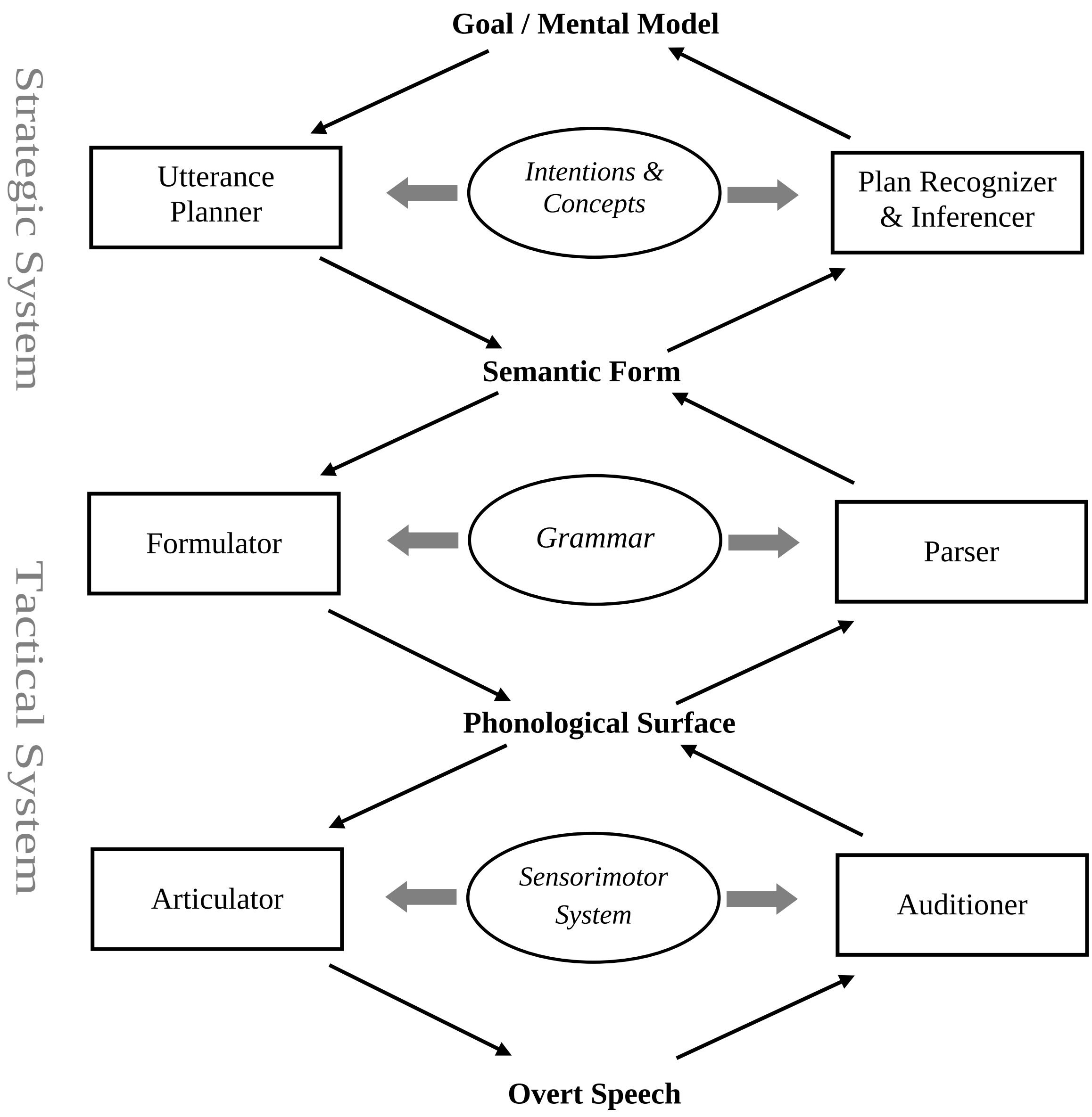

Figure 1: Architecture of the Human Language Faculty

As can be seen from figure 1, at least three cognitive subsystems are involved in language production and language interpretation. The conventional basic idea is that (spoken) language is a way to convey thoughts through sounds. Hence, language involves the system of grammar (with its linguistic representations discussed in section 5), the system of thoughts (with its mental representations discussed in section 6) and the system of sound perception and production (with its sensorimotor representations discussed in section 4). We propose that the language model of figure 1 is bidirectional for all three declarative subsystems, i.e. the knowledge schematized in the elliptical forms is used in two directions of processing: comprehension and production.

In the comprehension direction the *auditioner* maps overt speech (represented as an overt form) to a phonological surface form. The *parser* maps this form to a semantic representation which forms the input for the *inferencer and plan recognizer*. These mechanisms identify the mental model (Johnson-Laird, 1981) underlying the interpretation of the utterance and the corresponding speech act (Searle, 1969).[2] In the production direction the utterance planer decides what to say and the formulator/articulator decide how to say it.[3] More precisely, the formulator maps the semantic representation to the phonological surface and the articulator forms the spoken output from it.

It should be emphasized that the architecture scheme in figure 1 shows merely a relevant subpart of the *representations* that are involved in language understanding and language production and the links between these representations. The illustration should no be misunderstood as showing the *processes* that go on in comprehension and interpretation. For example, it would be very naïve to assume that language generation starts with the complete goal/mental model that underlies the intended utterance, and then goes on by developing the consecutive levels in a serial ordering. In a famous essay, Heinrich von Kleist (2002) cites politicians who often start speaking without knowing what they want to say. However, having started to speak often helps them to find out what they want to say (without interrupting their flux of speaking). Von Kleist speaks of "I´idée vient en parlant". Evidently, any explication of a relevant process should be happen *at the background* of the picture rather than *in* it. Obviously one could illustrate semantic change or sound change using the picture, but the picture itself does not show the process. What we are after is the representations, and the logical links between them, because we consider them to be prior to the processes.[4]

3 Bidirectional Optimization and Fossilization

Standardly, OT specifies a relation between two abstract entities, an input and an output. This relation is drawn upon two formal mechanisms, **GEN** and **EVAL**. GEN (for Generator) creates possible output candidates on the basis of a given input. EVAL (for Evaluator) uses the particular constraint ranking of the universal set of constraints **CON** to select the best candidate for a given input from among the candidate set produced by GEN. In phonology and syntax, the input to this process of optimization is an underlying linguistic representation. The output is the (surface) form as it is expressed. Hence, what is normally used in phonology and syntax is unidirectional optimization where the view of the speaker is taken. This contrasts with OT semantics where the view of the hearer is taken as the sole direction of optimization (de Hoop & de Swart, 2000; Hendriks & de Hoop, 2001).

The following example gives a simple illustration of how the theory works and how the required devices look like. The example concerns the grammar component with a defined mapping between forms and meanings. Assume we have two forms f_1 and f_2 which are semantically equivalent. This means that **GEN** associates the same interpretations with them, say m_1 and m_2. We stipulate that the form f_1 is less complex (less marked) than the form f_2 and that the meaning m_1 is less complex (less marked) than the meaning m_2. This is expressed by two markedness constraints: F for forms and M for meanings – F prefers f_1 over f_2 and M prefers m_1 over m_2. This is indicated by the two leftmost constraints in table 1.

[2] Alternately, we could consider *perceptual simulations* (Barsalou, 1999) instead of mental models as the basic mental entities underlying conceptual processing.

[3] This is the famous distinction between *strategy* and *tactics* which has been adopted in some form in nearly every language generation system built to date (e.g. McKeown, 1985).

[4] Thanks to Paul Boersma for clarifying these points to one of the authors in an email conversation.

	F	M	F→M	*F→*M	F→*M	F*→M
$<f_1, m_1>$					*	
$<f_1, m_2>$		*	*			
$<f_2, m_1>$	*			*		
$<f_2, m_2>$	*	*				*

Table 1: Markedness and linking constraints in a 2-forms × 2-interpretations design

Besides the markedness constraints, four so-called linking constraints can be formulated. There are precisely four independent linking constraints in the present example. The linking constraint F→M says that simple (unmarked) forms express simple interpretations. The constraint *F→*M says that complex forms express complex interpretations. The two remaining linking constraints express the opposite restrictions. In the present case linking constraints can be seen as lexical stipulations that fix a form-interpretation relation in an instance-based way.

Now let's assume that the two marking constraints outrank all the linking constraints, i.e. {F,M} >> {F→M, *F→*M, F→*M, F*→M}. Unidirectional optimization then gives the pairings indicated in figure 2a. The pairings realise what Smolensky (1996) considered as the initial state of the learner: every meaning is expressed by the simplest possible expression and every expression is assigned the simplest possible meaning.

The strong version of bidirectional OT (Blutner, 2000) selects all pairs which are optimal from both the listener's and the hearer's perspective. Figure 2b shows the corresponding diagram where only one pair comes out as strongly optimal, namely $<f_1, m_1>$. The potential pairs $<f_2, m_1>$ is blocked by the cheaper expression variant $<f_1, m_1>$, and the potential pair $<f_1, m_2>$ is blocked by a cheaper meaning variant (again $<f_1, m_1>$). Hence, strong bidirection correspond to the case of total blocking. Examples are the blocking of **furiosity* by *fury or* **fallacity* by *fallacy*, where all potential meanings are blocked. Furthermore, bidirectional optimization accounts for the phenomena of ineffability (a semantic input does not yield a well-formed syntactic expression as its output) and unintelligibility (a form with no corresponding meaning) in a straightforward way (Beaver & Lee, 2004; de Hoop, 2001). However, the proposed symmetric version of bidirection cannot account for synonymy and ambiguity. If there are any differences in the complexities of the different meanings, then no form can be ambiguous since only one meaning can be selected as the optimal interpretation. Similarly, if there are any differences in the complexities of the different forms, then synonymy cannot exist since each meaning can be expressed by maximally one optimal form.

Figure 2c shows the pairings under a simple version of *asymmetric* OT where the listener uses unidirectional optimization but the speaker does it bidirectionally, i.e. he restricts his own optimal productions by checking if he can understand them appropriately. In the given example the model yields synonymy (m_1 is expressed by f_1 and f_2) and ineffability (m_2 cannot be expressed). This form of asymmetric OT exhibits Speaker-altruism, i.e. it conforms to a strategy of the speaker that simplifies the task for the listener but makes it more effortful for the speaker.[5]

[5] In the literature, different forms of asymmetric OT have been proposed. For instance, Hale & Reiss (1998) and Zeevat (2000) propose an variant where the hearer takes the listener crucially into account (similar to motor theories of perception). For a critical discussion the reader is referred to Beaver & Lee (2004) The present form of the asymmetric OT comes close to Wilson's (2001) model.

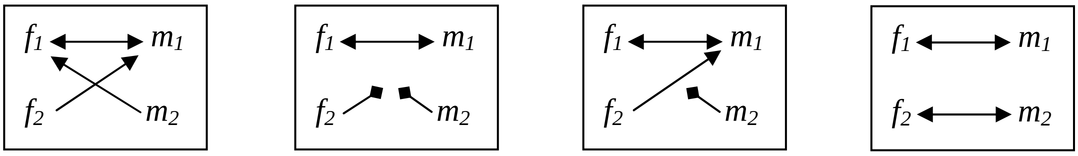

Figure 2: (a) unidirectional optimization; (b) strong bidirection; (c) asymmetric OT; (d) weak bidirection (superoptimality);

Kiparsky (1983) cites examples of *partial blocking* where a special (less productive) affix occurs in some restricted meaning and the general (more productive) affix picks up the remaining meaning (consider examples like *refrigerant* - *refrigerator*, *informant* - *informer*, *contestant* - *contester*). McCawley (1978) collects a number of further examples demonstrating the phenomenon of partial blocking outside the domain of derivational and inflectional processes. For example, he observes that the distribution of productive causatives (in English, Japanese, German, and other languages) is restricted by the existence of a corresponding lexical causative (the famous *kill/cause to die* example).

Weak bidirection is an iterated version of strong bidirection and provides a solution concept that produces partial blocking instead of total blocking. Figure 2d shows the corresponding diagram. Originally, the idea of weak bidirection was culled off from the basic principles of neo-Gricean pragmatics (Blutner, 1998) devoted to language change. A form meaning pair is considered *superoptimal* if it is not blocked by any superoptimal expression/meaning variant of it. Note the recursive character of this definition mentioning the definiens also in the definiendum (cf. Jäger, 2002). It is simple to see that all strongly optimal pairs are also superoptimal. However, there can be superoptimal pairs that aren't strongly optimal, such as the pair $<f_2, m_2>$ in figure 2d. In pragmatics, weak OT captures the essence of the pragmatic generalization that "unmarked forms tend to be used for unmarked situations and marked forms for marked situations" (Horn 1984:26).

It is a common observation that there are *asymmetries* between comprehension and production. For instance, we are often not able to produce what we can understand. The opposite situation, where we can produce a certain expression but we cannot understand this expression properly, is also possible though it is observed much less often. Interestingly, the phenomenon of aphasia gives a feasible illustration of the existence of both kinds of asymmetries (e.g. Jakobson, 1941/1968). Likewise, in the domain of language acquisition both sides of the phenomenon can be detected. It is well known that children's ability in production lags dramatically behind their ability in comprehension (e.g. Benedict, 1979; Clark, 1993). It was only recently that attention was also paid to the opposite case where children's comprehension performance lags years behind their ability of production (Hendriks & Spenader, 2005/2006) .

Unidirectional OT has a very simple answer to the question of how to explain differences between comprehension and production at a certain stage of development. In order to account for the usual observation that comprehension can be perfect while production is not, Smolensky (1996) assumes markedness constraints for forms only, as well as linking (faithfulness) constraints – linking forms and meanings in an adequate way. He also assumes that the markedness constraints initially dominate the linking constraints. It is exactly under these conditions that we get the expected pattern. This will be demonstrated by going back to our earlier, abstract example with two forms and two meanings.

We assume the markedness constraint F for forms and the two linking constraints F→M and *F→*M (see table 1). If we further assume the ranking {F} >> {F→M, *F→*M}, the result is that the comprehension is always correct, i.e. f_1 is interpreted as m_1 and f_2 is interpreted as m_2. However, the production perspective sometimes gives the wrong result. This is because of the dominance of the markedness constraint F, which gives the result that all meanings m_i (i = 1,2) are expressed by the simpler form f_1. Figure 3a shows the corresponding pairings in this case of so-called *delayed production*.

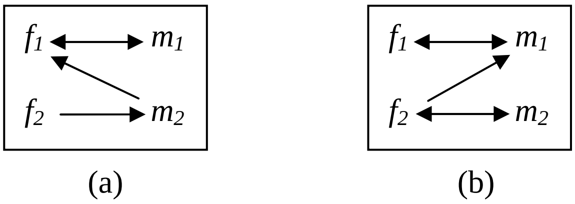

Figure 3: Asymmetries in unidirectional optimization: (a) a case of delayed production; (b) a case of delayed comprehension

Interestingly, the opposite pattern – called *delayed comprehension* – is also possible (see figure 3b). In this case we have to assume an incomplete system of linking constraints that outranks the system of markedness constraints. A very simple example is {F→M} >> {F}. Now m_1 produces f_1 and m_2 produces f_2. However, while f_1 is always interpreted correctly as m_1 the form f_2 comes out as ambiguous. It can be interpreted both as m_1 and m_2.

The modifier 'delayed' in delayed production/comprehension suggests that there is a mechanism available that can overcome the asymmetry between production and comprehension at some point of the temporal development of the language system. Indeed, there are two such mechanisms that have been discussed recently. The first mechanism is a mechanism of *maturation* resulting in a processing system that integrates the comprehension and the production perspective (cf. Hendriks & Spenader, 2005/2006). The result of maturation is the symmetric system of strong bidirectional processing. Alternatively, it also could be the asymmetric system exhibiting Speaker-altruism.

The second mechanism is based on OT learning and leads to a reranking of the involved constraints (e.g. Smolensky, 1996). Basically, the (iterated) learning mechanism leads to the phenomena of conventionalization, fossilization, reanalysis, or reconstruction, and we will discuss its relevance for the different parts of the language faculty in the following sections. Interestingly, the (recursive) concept of weak bidirection comes close to the capacities of the second mechanism. Hence, we propose not to interpret weak bidirection as an online mechanism of language processing but as an offline mechanism that has to do with iterated learning and diachronic change.

Which of the two proposed mechanisms is really responsible for overcoming the empirically attested asymmetries between comprehension and production? This is an important research question and we will try to answer it in the following sections.

4 Bidirection and the Sensorimotor System

Following Boersma (1998) we assume two kinds of phonetic representations: auditory form and articulatory form. The auditory form is a sequence of events relating to the perception of qualities such as pitch, timbre, consonance, and phonetic identity. Contrastingly, the articulatory form is a sequence of gestures of the articulatory apparatus, i.e. a description of the relevant muscle activities affecting the glottis, the larynx, the tongue tip, the tongue body, the velum etc. Following Boersma, we will assume sensorimotor constraints describing our knowledge of what our articulations will sound like and conversely – taken bidirectionality of the corresponding knowledge system into account – describing how to implement articulatorily sounds we aim to produce. Furthermore, a phonological surface form level is assumed to constitute the interface between the system of grammar and the sensorimotor system. As usual, we will take the surface form to be a structure of abstract phonological elements such as phonological features, segments, syllables, and feet. Figure 4 gives a very schematic and simplified picture of the sensorimotor system.

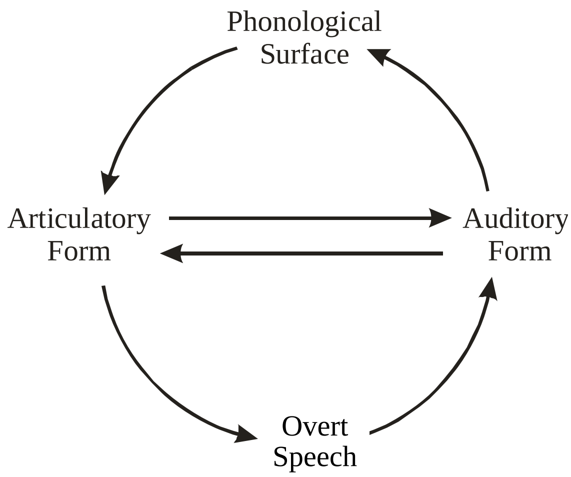

Figure 4: The sensorimotor system: the speaker's perspective maps the phonological surface onto the articulatory form which produces the overt speech; the listener's perspective maps the overt speech onto the auditory form which is interpreted as phonological form.

The mapping between the phonological surface and the articulatory form is restricted by *articulatory constraints*, and the mapping between the phonological surface and the auditory form is restricted by *cue constraints* (cf. Boersma, this volume).

By using the same system of cue constraints both in perception and in phonetic implementation Boersma & Hamann (2007) show that the bidirectional use of cue constraints leads to two asymmetries between perception and production, namely the *prototype effect* and the *articulatory effect*. The prototype effect describes "the phenomenon that the learner's preferred auditory realization of a certain phonological category is more peripheral than the average auditory realization of this category in her language environment" whereas the articulatory effect "limits the auditory form to something that is not too difficult to pronounce". Further, Boersma & Hamann demonstrate that languages that are evolutionary stable over the generations have to cancel these two biases out against one another. This results in a balance between *distinctivity* and *articulatory effort*. Interestingly, this is derived without the assumption that the learner has any knowledge of auditory distances or any other goal-oriented dispersion mechanism in the whole system.

Whereas the work by Boersma & Hamann (2007) demonstrates the role of bidirectional constraints and bidirectional learning in the sensorimotor system, it does not give a direct hint about bidirectional online processing in perception/production. For example, we could ask whether the listener takes the speaker into account when percepting the stream of overt speech. This question asks for the adequacy of motor theories of speech perception (e.g.

Liberman & Mattingly, 1985). As pointed out by Tatham & Morton (2006) these theories (and similar analysis-by-synthesis theories) come into trouble when it comes to revealing the kind of invariance needed to uniquely identify phonological objects. Even if extended further these theories seem to be unable to handle more complex issues such as prosody or expressive content. Furthermore, from the point of view of artificial speech understanding systems, these theories are extremely cumbersome and time consuming even for modern digital computers and therefore unsuitable for modelling automatic, incremental natural language perception.

Let's consider now the converse question of whether the speaker takes the listener into account when producing the stream of overt speech. The existence of monitoring devices that evaluate the appropriateness or correctness of ongoing motor activity or response provides convincing evidence for an affirmative answer. In the language domain, for instance, monitoring can manifest itself in the phenomenon of self-repair in speech (Levelt, 1983). Levelt discriminates two kinds of selfrepairs: *overt* and *covert*. In overt selfrepairs, speech is interrupted and a new attempt is made at producing the correct form (e.g., 'I saw him…I saw her writing a letter). Covert repairs are self-repairs in which errors are intercepted at the level of planning by an inner monitoring mechanism. This inner monitoring mechanism operates via prearticulatory editing. Covert repairs are manifested in various speech disfluencies such as prolongations or pauses. Characteristic is the early moment of these repairs, sometimes just one phoneme has been produced before the repair occurs.

Levelt's (1983) 'perceptual loop theory' localizes monitoring in the perceptual apparatus. Hence, figure 4 can be seen as bidirectional OT reconstruction of this theory. We can identify an inner and an outer loop of speech generation. The inner loop starts with the phonological surface and produces an articulatory representation. This representation is mapped by the sensorimotor constraints to the auditory form and leads back (perception mechanism) to a phonological surface representation triggering the monitoring process and possibly the repair mechanism. The outer loop takes longer for processing and also includes real articulation of speech. Recently, Hartsuiker and Kolk (2001) have provided computational evidence for Levelt's perceptual loop theory. We will interpret the empirical and computational empirical evidence as suggesting the validity of asymmetric OT in the sensorimotor domain.

We make errors in production, and we also make errors in perception. As to language, we occasionally misread or mishear. To avoid miscommunication, it is important to detect such misperceptions. Does this suggest – similarly to monitoring in production – that we can detect such misperception by taking the production direction into account, i.e. by assuming an analysis by synthesis mechanism? Following Van Herten, Chwilla, & Kolk (2006), we think that in perception there is just one representation, derived from the input sentence. However, there can be a strong conflict between what is perceived and what is expected to signal the presence of a possible misperception. Hence, it is the context which can trigger reanalysis in case of misperceptions. Of course, this idea does not necessarily exclude an analysis-by-synthesis mechanism, but it makes it tremendously superfluous.

What about the idea of fossilization? In the sensorimotor domain this idea corresponds to the reanalysis picture which is quite interesting. As a case in point consider the reanalysis that occurs when in generation a certain effect (say, lengthening of a short – i.e. monomoraic vowel) is "just phonetic", and the next generation step reinterprets this as a phonological effect (say, a long – bimoraic – vowel).[6]

Concluding this section we claim that the existence of certain monitoring devises strongly suggests that a restricted online version of bidirection is correct: speakers optimize bidirectionally and take the listener into account whereas there is no evidence hat listeners take the speaker into account. Further, examples of reanalysis suggest that the non-supervised

[6] Thanks to Paul Boersma for suggesting us this example.

learning mechanism can systematically rebuild and restructure the bidirectional constraints of the sensorimotor system.

5 Bidirection and Grammar

According to Jackendoff (2007) the objective of natural language processing is "to produce a correlated set of phonological, syntactic, and semantic structures that together match sound to meaning" (Jackendoff, 2007: 3). Following standard terminology the bidirectional knowledge system that describes the correlation of sound and meaning is called *grammar*. Because this correlation is mediated by syntactic structure, the processor must develop a sufficient amount of syntactic structure in both perception and production in order to realize the mapping between sound and meaning. According to Jackendoff's parallel architecture

(i) the grammar is made up of *independent generative components* for phonology, syntax, and semantics, linked by *interfaces* (modularity)
(ii) the grammar is *constraint-based* and *inherently nondirectional*.

We have to modify these two claims only moderately in order to transform Jackendoff's architecture into the OT picture. First, we accept the idea of modularity in a very weak sense: the generators that produce the different types of inventories and structures are independent generative components. Second, we assume a grammar based on bidirectional constraints. However, we assume that the constraints are violable rather than strict. This naturally leads to the idea of constraint interaction. As most researchers in OT we do not assume that the constraints are organized in a modular way, so that there are separate and encapsulated modules for phonological, syntactic, and semantic constraints. Rather, the constraints are assumed to be *cross-modular*, i.e. they involve a mix of syntactic, semantic, and pragmatic information (Blutner, de Hoop, & Hendriks, 2005).

In Jackendoff's system special *interface rules* are introduced to correlate phonological structures with syntactic structures on the one hand and syntactic structures with semantic structures on the other hand. In figure 5 these interfaces are indicated by double arrows with bold lines. According to the cross-modular architecture of the OT system we also have to assume a third kind of correlation that directly connects aspects of the phonological structure with aspects of the semantic structure. [7] This is indicated by double arrows with dashed lines in figure 5 (in order to signal the deviation from Jackendoff's system).

[7] A good example for the direct correlation between phonological structures and semantic structures (focus) is given by Beaver, Clark, Flemming, Jaeger, & Wolters (2007).

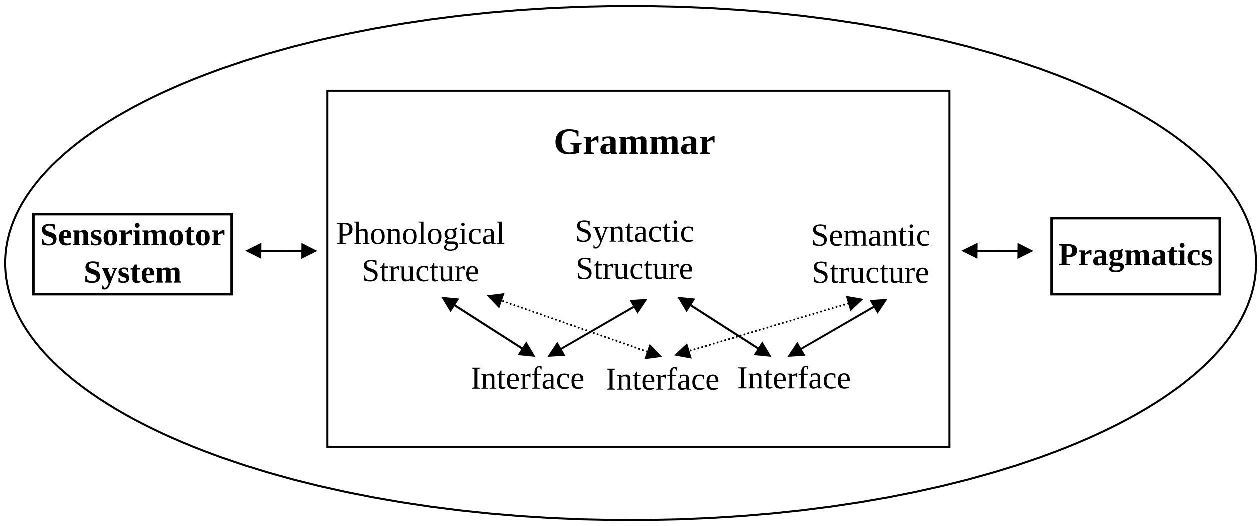

Figure 5: Jackendoff's parallel architecture (adapted from Jackendoff, 2007)

In the present OT variant of Jackendoff's parallel architecture, the interfaces are realized by certain constraint systems that are organized in a cross-modular way, i.e. the rankings of these constraints corresponding to the different interfaces can be completely mixed. Hence, some subset of syntactic constraints can overpower some subset of semantic and phonological constraints whereas another subset of syntactic constraints can be overpowered by a certain subset of semantic or phonological constraints. A similar parallel structure has been proposed by Boersma (this volume) where the semantic structures are restricted in the domain of morphemes.

Quite in agreement with ideas proposed by Goldberg (1995) and Jackendoff (2007) we assume that there is no strict lexicon/grammar distinction: morphemes and words corresponds to relatively idiosyncratic constraints in a continuum of generality with more general grammatical constraints. A side effect of his decision is that it opens a simple way to approach grammaticalization and reanalysis phenomena in the area of syntax/semantics. For example, lexical elements can be reanalyzed as grammatical ones. Following Detges & Waltereit (2002) we will see grammaticalization as a speaker-based phenomenon and reanalysis as a hearer-based procedure. Like any type of change, grammaticalization is ratified by reanalyses on the part of listeners. In this sense we consider reanalysis and grammaticalization as inseparable twins.

The idea of bidirectional constraints and bidirectional learning has been demonstrated in simulation studies by Zeevat & Jäger (2002) and Jäger (2004). The results of these studies suggest that certain syntactic alignment patterns can be explained completely in a functional way making us of the bidirectional gradual learning algorithm. However, these studies do not allow for a clear prediction on the amount of bidirectionality in online processing.[8] Before we

[8] Jäger's (2004) bidirectional gradual learning algorithm involves interpretation as well as generation. For the interpretation the standard unidirectional optimization is used whereas bidirectional optimization is used for the generation. Only in cases where no bidirectional solution exists the unidirectional solution is used. Boersma & Hamann (2007) comment on this procedure as follows: "However, Jäger's Bidirectional Gradual Learning Algorithm relies on a slightly teleological feature of evaluation in production: every candidate form in a production tableau has to be hearer-optimal, i.e. if taken as the input to a comprehension tableau (with the same rankings) it should be mapped to a meaning identical to the input of the production tableau. This explicitly listener-oriented evaluation procedure thus militates against ambiguous (i.e. poorly 'dispersed') forms in production, and Jäger relies on it for establishing the diachronic emergence of pragmatic case marking (which

discuss some relevant experimental work let's shortly discuss this question from the point of view of computational linguistics.

There is an old problem with assuming full symmetric bidirectionality to phonological and syntactic processing in both directions. In phonology, the problem is mostly discussed as the Rad/Rat problem. It appears in languages with final devoicing like Dutch or German. The German word Rat (council) is pronounced as [rat] without any change from the underlying form to the surface form. The word /Rad/ (wheel) is pronounced in the same way but here two constraints come into play: the *devoicing constraint* that prefers the pronunciation [rat] to [rad] and *faithfulness* that would prefer the pronunciation [rad] and that is outranked by *devoicing* in German. If we want to apply the same constraints in the direction from pronunciation to optimal underlying form, /Rat/ is always preferred because *faithfulness* in interpretation. The same problem can arise with syntactic ambiguities (Zeevat, 2000). Again in German, the sentence (1a) is ambiguous between the two readings given in (1b) and (1c):

(1) a. Welches Mädchen mag Oskar?
    b. Which girl likes Oskar?
    c. Which girl does Oskar like?

There are different strategies to avoid or to resolve the Rad/Rat problem and its syntactic counterpart. Obviously, the role of context is important in discussing this problem. If we assume that context acts as an external parameter, then we can solve the problem by assuming that in some context, /Rat/-reading is preferred and in another context the /Rad/-reading is preferred. The ambiguity of [rat] is simply explained then by the observation that in some context the optimal interpretation is /Rat/ and in another context it is /Rad/. To get this idea working we have to assume a constraint that directs the fitting of the context and can overpower phonological and syntactic constraints (conforming to the idea of a cross-modular constraint organization). This view draws, obviously, on a particular view of ambiguity. It sees ambiguity as an artifact that shows up when we abstract from context. Under fixed contextual conditions there is no real ambiguity. Interestingly, this argument is much stronger in connection with syntactic ambiguities like (1) where many (naive and untrained) people get the two interpretations only if we construct two different contexts for them.[9]

The Rad/Rat problem was originally raised by Hale & Reiss (1998). The solution they proposed is close to an analysis-by-synthesis procedure: to comprehend a surface form like [rat] requires the generation of a list of underlying forms that produce the same surface form. In the present case both underlying forms /Rat/ and /Rad/ yield the requested surface form [rat], so both are optimal comprehension candidates, to be disambiguated higher up by syntactic, lexical-semantic, or pragmatic constraints.[10] Hale & Reiss note that this solution is consistent with well-established priming effects: ''The general picture of lexical access during speech perception, then, is that it initially can discriminate only on phonological grounds. Only somewhat later in processing, after the syntactic and conceptual processors have gotten access to the list of possible candidates, can the ultimate choice of word be determined'' (Jackendoff, 1987: 103)

Hale & Reiss argue against any appeal to top-down processing to resolve the Rad/Rat problem. However, this argumentation is not correct since (i) a strong biasing context can select the appropriate reading immediately without activating the other readings, (ii) in cases where the ambiguous target word is not in the center of attention even a weak disambiguating

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enhances the semantic contrast between subject and object). It would be interesting to investigate whether our arguably simpler procedure (optimize comprehension only, then just speak) would be able to handle the complex cases that Jäger discusses."

[9] A similar solution is proposed by Boersma (this volume).

[10] A similar account is taken by Zeevat (2000; this volume)

context is strong enough to select the appropriate reading without activating the non-appropriate readings (Blutner & Sommer, 1988). And that is exactly what our first solution predicts by using cross-modal constraints for contextual selection.

A third solution was proposed by Bouma (2008). Following ideas put forward by Antilla and colleagues (Antilla & Cho, 1998; Anttila & Fong, 2000) Bouma assumes underspecified, partial rankings that can be described by putting constraints in so-called strata. Using stratified grammars it is possible to achieve ambiguity in comprehension even if bidirectional optimization is taken into account. Unfortunately, Bouma (2008) does not discuss a learning theory for stratified grammars. This makes an evaluation of this theory difficult since the bidirectional learning account is crucial for many applications of bidirection including fossilization phenomena.

Taking the intriguing debate about the Rad/Rat problem and related problems into account makes it is not easy to draw any clear conclusions concerning the question on the amount of bidirectionality in online processing. In the final part of his section we will discuss this question in the light of recent findings in psycholinguistics. The basic idea of a psychologically realistic theory of OT is the postulate “that the parser's preferences reflect its attempt to maximally satisfy the grammatical principles in the incremental left-to-right analysis of a sentence” (Fanselow et al., 1999). In OT syntax the production perspective is normally taken. It optimizes syntactic structures with respect to a semantic input. In natural language parsing, naturally, the comprehension perspective is adopted. That means the parser optimizes underlying structures with respect to a surface input. Gibson & Broihier (1998) and Fanselow, Schlesewsky, Cavar, & Kliegl (1999) have shown that parsing preferences can be explained in this way, and the latter group of authors has convincingly demonstrated that the same constraints seem to be used both in OT syntax and in parsing. This is a powerful argument supporting the psychological reality of an OT grammar.

At this moment there is no need to include the Speaker’s perspective in order to account for parsing preferences and garden path effects. Moreover, the idea of robustness of comprehension (Smolensky, 1996; Tesar & Smolensky, 2000) suggests that even ungrammatical sentences can be parsed (using unidirectional, interpretive optimization). However, for realizing that a given sentence is ungrammatical the other direction (speaker’s perspective) becomes relevant. Since grammaticality judgments are not part of the normal comprehension process they are normally classified as offline phenomena. In the previous section we have seen that things are possibly different in production. In the present case the existence of a syntactic repair mechanism (e.g. Friederici, Hahne, & Saddy, 2002) suggest a similar conclusion: as speakers we automatically understand what we say.

The existence of a syntactic repair mechanism (conforming to the existence of bidirectional processing in production) does not mean that speakers always avoid temporarily ambiguous, difficult to comprehend sentences. Normally, only a few speakers include the *that*-complementizer in sentences such as (2):

(2) a. The coach knew (that) you missed practice
    b. The coach knew (that) she missed practice

When sentences with sentence complements are produced in their reduced form – i.e. without the optional function words – they may constitute garden path sentences as example (2a) shows. Hence, the use of *that* avoids the temporary ambiguity in example (2a). Example (2b) does not exhibit this temporary ambiguity since the pronoun *she* occur in complementary distribution with respect to subject versus object roles. Hence, if speakers tend to avoid temporary ambiguities (modeled by bidirectional, incremental processing) they should produce significantly more optional function words in examples like (2a) than in examples like (2b).

In a recent study by Ferreira & Dell (2000) a *sentence recall paradigm* was used to test this hypothesis. Surprisingly, no significant difference was found suggesting that speakers are selfish, exploiting the flexibility of language to ease only the task of creating sentences. However, if the "communicative pressure" was manipulated and increased (Experiment 6), this affected optional word mention in the expected direction. Hence, speakers can change their overall level of *that*-mention when understandability is important. Under this condition bidirectionality seems to be important in incremental *sentence production*. We see no relevant experiment that analogously demonstrates the need for bidirectionality in incremental *natural language parsing*.

6 Pragmatics in OT

In OT pragmatics, the bidirectional view of optimization is motivated by a reduction of Grice's maxims of conversation to two principles: the R-principle, which can be seen as the force of unification minimizing the Speaker's effort, and the Q-principle, which can be seen as the force of diversification minimizing the Auditor‘s effort (e.g. Atlas & Levinson, 1981; Horn, 1984). Hence, OT pragmatics can be considered as a formalization of the neo-Gricean view of pragmatics (Blutner, 2000). In terms of OT pragmatics, the idea behind interpretive optimization is to select the most coherent interpretation. What is meant by coherence has to be expressed by particular OT constraints, such as formulated, for instance, by Zeevat (2007). The principle of interpretive optimization is a very abstract one which has to be supplemented by a system of ranked constraints in order to constitute a system that is able to express something like Horn's R-principle. The simultaneous use of expressive optimization can be seen as similar to the role of Horn's Q-principle - it acts as a blocking mechanism which blocks all the outputs which can be expressed more economically by an alternative linguistic input. Again, what counts as more economical has to be expressed by the system of constraints.

In the previous sections we have stressed two different ways of interpreting bidirectional optimization: (1) as a psychologically realistic online mechanism; (2) as a mechanism taking place offline, e.g. during language acquisition – if repeated it is *fossilizing* the optimal form-interpretation pairs. Besides unidirectional optimization, we have suggested strong bidirection and asymmetric bidirection for the former mechanism (cf. section 3, especially figure 2a-c). The solution concept of weak bidirection was suggested to capture the fossilization and the diachronic dimension of language (Blutner, 2000, 2007a, 2007b; Blutner & Zeevat, to appear). Weak bidirection captures the essence of the pragmatic generalization that "unmarked forms tend to be used for unmarked situations and marked forms for marked situations" (Horn 1984:26).

There are at least two – or even three – arguments against viewing weak bidirection as describing online pragmatic processing. First, a repeated and conscious change of perspective cannot take place online because of the enormous processing resources that are required for it. This point is similar to those made for the system of grammar by Kuhn (2003). Second, assuming that natural language interpretation happens on an incremental, left to right basis, conflicts with the non-local, global nature of the proposed algorithms which calculate the super-optimal solutions (cf. Beaver & Lee, 2004). Third, there are certain examples of anti-iconicity showing that Horn's division of pragmatic labor and the idea of week bidirection formalizing it are not completely correct and should be seen as an approximation only. The approximation seems to be good enough in cases where markedness and frequency are correlated such that the marked structures are the less frequent ones. Both instances of iconicity and anti-iconicity can be explained when an evolutionary setting is assumed (Benz, 2003; Blutner, Borra, Lentz, Uijlings, & Zevenhuijzen, 2002; Van Rooy, 2004). In this approach the solution concept of weak bidirection is considered as a principle describing the results of language change: super-optimal pairs emerge over time in language change. This relates to the view of Horn (1984) who considers the Q and the I principle as diametrically opposed forces in language change, and it conforms to the idea that synchronic structure is significantly informed by diachronic forces. Interestingly, frequency is the decisive factor in these models.

One important instance of anti-iconicity has been found in connection with semantic broadening where the initial meaning is described as that of an ideal shape, figure or state. A good example can be found in Dutch, where besides the preposition *om* (= Engl. *round;* German *um*) the expressions *rond* and *rondom* are in use. The expression *rond* is a word borrowed from French. It refers to the ideal shape of a circle. Starting with its appearance it comes in competition with the original (and *unmarked*) expression *om*. The results is a division of labour as demonstrated in the following examples (Zwarts, 2003, 2006):

(3) a. Ze zaten rond (?om) de televisie
They sat round the television
b. Een man stak zijn hoofd om (?rond, ?rondom) de deur
A man put his head round the door
c. De auto reed om (?rond, ?rondom) het obstakel heen
The drove round the obstacle
d. het gebied rondom (?om) het stadje
the area round the little town

According to the principle of iconicity we would expect that the unmarked form (*om*) is paired with the ideal of the circle shape and the marked form (*rond*) with the detour interpretation.[11] However, the opposite is true. There is a simple explanation of this fact: ideal shapes/situations are much less frequent then non-ideal situations; hence, since the probabilities are $P(m_1) < P(m_2)$, the evolutionary approach predicts anti-iconicity. Concluding, our third argument is that weak bidirection is best modelled by a mechanism of cultural evolution, an offline mechanism, of course.

What is a psychologically realistic picture of online interpretation/production in connection with the pragmatic tasks? We think recent work by Hendriks and colleagues about the use and acquisition of binding principles (Hendriks, Englert, Wubs, & Hoeks, 2007; Hendriks, Rijn, & Valkenier, 2007; Hendriks & Spenader, 2005/2006) allows concluding that the variant of an asymmetric OT introduced in section 3 gives the proper answer (Blutner, 2007b). The argument rests on a careful investigation of production/comprehension asymmetries that can be found in connection with some data on binding phenomena.

Let's start with a case of delayed production that demonstrates that comprehension can be perfect while production is not. A good example is given by production and understanding of R-expressions and pronouns as illustrated in (4).

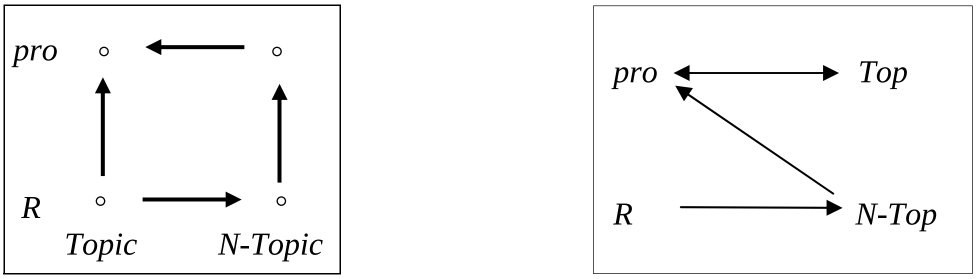
(4) Discourse context: A woman is waiting at the corner. Her girl is eating an ice cream cone.
a. She wears a red shirt.
b. The woman wears a red shirt.

The interpretation of the pronoun in (4a) clearly refers to the discourse topic (*the girl*). If we want to express the alternative meaning as in (4b) we cannot use the pronoun. Interestingly,

[11] The assumption that the ideal path description (circle) is realizing the unmarked interpretation and the detour interpretation is realizing the marked interpretation is justified by independent thoughts about the preference of the logically strongest interpretation (e.g. Dalrymple, Kanazawa, Kim, Mchombo, & Peters, 1998).

young children very often produce such subject pronouns when intending to refer to non-topics. Karmiloff-Smith (1985) found this pattern of production in children until the age of 6.

As we have mentioned in section 3, the phenomenon of delayed production can be modeled by assuming markedness conventions that initially dominate linking constraints (see figure 3a). In the present case, f_1 stands for the pronoun and f_2 for an R-expression. Further, m_1 is the interpretation referring to the topicalized discourse referent while m_2 refers to the non-topicalized one. The markedness constraint F can be seen as referential economy (preferring pronouns to R-expressions), F→M expresses the preference for pronouns to be interpreted as the topic of the discourse and and *F→*M expresses the preference for R-expressions to be not topicalized. Figure 6a shows the preferences between the four possible form-interpretation pairs that results from assuming that markedness is initially higher ranked than linking. Using unidirectional optimization, the diagram describes the OT system of an agent who can properly understand pronouns and R-expressions but who overuse pronouns when intending to refer to non-topics. Figure 6b shows the predicted asymmetry between production and interpretation (note that figure 6b is instantiating figure 3a).[12]



(a) (b)

Figure 6: (a) Preferences between the four form-interpretation pairs based on the system {PRO} >> {PRO→TOP, *PRO→ *TOP} of ranked constraints; (b) Asymmetries in unidirectional optimization calculated from the same system of ranked constraints

In section 3, we introduced two models for describing the transfer from the (asymmetric) child system to the adult system. First, the online processing model overcomes the asymmetry by assuming that the speaker takes the hearer into account and begins to reason bidirectionally at some point of her development. Second, the fossilization view says that unidirectional optimization is sufficient if it is assumed that there is an (iterated) learning mechanism that reranks the corresponding constraints in a proper way. In the present example the linking constraints are promoted and the markedness constraints are demoted, resulting in the system {PRO→TOP, *PRO→ *TOP} >> {PRO}. Figure 7 shows the corresponding diagrams.

[12] The constraint *PRO → *TOP – saying the R-expressions refer to non-topicalized discourse referents – is not really required to derive the pairings shown in figure 6b because the content of the R-expression makes the proper choice. Hence, the system {PRO} >> {PRO→TOP} is sufficient to derive the proper pairings.

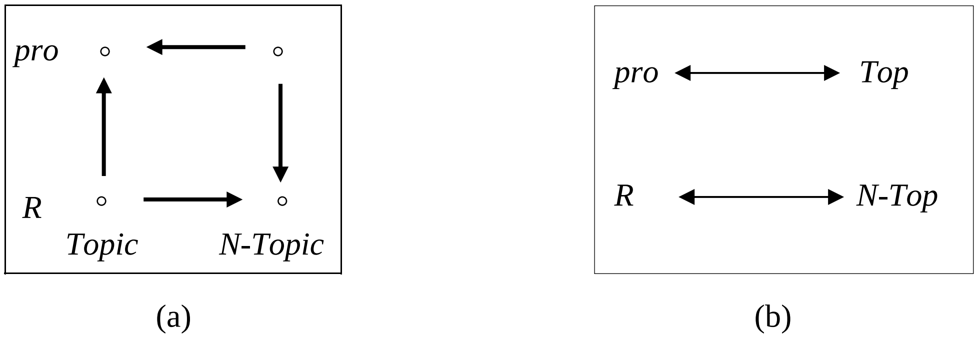


Figure 7: (a) Preferences between the four form-interpretation pairs based on the system {PRO→TOP, *PRO→ *TOP} >> {PRO} of ranked constraints; (b) Symmetric results of unidirectional optimization.

What empirical evidence can help to discriminate between the two models? In a recent research article, Hendriks, Englert, & Wubs (2007) argue that the investigation of elderly adults could be decisive. It can be assumed that elderly adults possess the required pragmatic and grammatical knowledge to select and interpret referring expressions. However, their linguistic performance can be defective, due to the decreasing working memory capacity. And indeed, the authors found that elderly adults produce non-recoverable pronouns significantly more often than young adults when referring to the old topic in the presence of a new topic. With respect to the comprehension task, no significant differences were found between elderly and young adults.

Obviously, this experimental outcome is a great problem for the fossilization view, since a stipulation of a mechanism of 'de-fossilization' does not make any sense in the present context. Consequently, the assumption that the speaker takes the hearer into account is well motivated for such examples. Hence, both strong bidirection and asymmetric bidirection introduced in section 3 are supported by the empirical evidence, and they are good candidate models for further investigation.

Next, let us consider the case of delayed comprehension that was been observed in connection with reflexives. A series of experiments has shown that children make errors in interpreting pronouns as late as age 6;6, yet correctly comprehend reflexives from the age of 3;0 (e.g. Chien & Wexler, 1990; Koster, 1993; McKee, 1992; Spenader, Smits, & Hendriks, 2007). For instance, children were confronted with sentences such as (5a) and (5b) and a corresponding picture with an elephant and an alligator was shown. In some trials on the picture the elephant was hitting himself.

(5) Discourse context: Here is an elephant and an alligator.
   a. The elephant is hitting himself.
   b. The elephant is hitting him.

In the experiment (Spenader et al., 2007) children until at least the age of 7 said that both sentence (5a) and sentence (5b) matched the picture showing an elephant hitting himself. Hence, the pronoun leads to errors in interpretation for the asked children. Contrasting with the comprehension data, language production experiments consistently have shown that children do not have problems in producing reflexives or pronouns correctly. For example, Bloom et al. (1994) demonstrated that even in the youngest age groups investigated (ranging from 2;3 to 3;10) the children consistently used the pronoun to express a disjoint meaning, while they used the reflexive to express a coreferential interpretation. It can be concluded from the production data that children have competence of binding principles. Why don't they use this knowledge in comprehension then?

An answer in terms of OT pragmatics was given by Hendriks & Spenader (2005/2006). As discussed in section 3 the case of delayed comprehension can be described by an incomplete system of linking constraints that outranks the system of markedness constraints. In the case under discussion Hendriks & Spenader assumed the markedness constraint called "referential ecomomy" (see Burzio, 1998). It prefers the reflexive over the pronoun. Further, principle A of binding theory was assumed as a violable constraint (excludes the reflexive from the disjoint interpretation), and it was assumed that linking dominates markedness. This leads to a diagram such as (3b) illustrating delayed comprehension.

Hendriks & Spenader assume the processing view with bidirectional optimization: the hearer takes the speaker into account. Unfortunately, this leads to a problem with the behavior of elder people, since it predicts that elder people should have problems in understanding pronouns, which obviously is wrong. Blutner (2007b) concludes from this observation that in this case the fossilization mechanism is the proper way of explaining.

Taken all things together, we claim that a combination of fossilization and asymmetric bidirection fits the available data best. The assumption that the speaker takes the hearer into account but not *vice versa* explains the data with the referring expression. The same assumption plus the idea of fossilization explains the reflexive pronoun data.

7 Conclusions

We have argued for conceptualizing the human language faculty as a bidirectional system, which can be used by processes of approximately equal computational complexity to understand and to generate utterances of a language.

Furthermore, we have discussed two principled ways of how (and when) the conflict between the two diametric Zipfean forces can be resolved. The first view (*bidirectional online processing*) suggests that this interaction takes place online during actual utterance interpretation/generation. The second view (*fossilization*) suggests that the conflict is resolved during bidirectional learning. We have argued that neither of these extreme views gives a complete fit to the know empirical data when taken *per se*. While it is obvious that fossilization phenomena are real to some extent, it can also be argued that a asymmetric online version of bidirection is correct: speakers optimize bidirectionally and take the hearer into account when enough processing resources are available for calculating the optimal expression. In contrast, hearers do not normally take the speaker into account when the optimal interpretation is calculated. This seems to be true for all the three cognitive subsystems involved in language production and language interpretation: sensorimotorics, grammar, and pragmatics. However, more empirical work is needed to decide this difficult issue.

Future work should be devoted to discuss the emerging interplay between fossilization and asymmetric bidirectional processing in terms of cognitive economy and cognitive resources. It appears that in particular cases it is more economical to store the relevant information directly in the long term memory (and to retrieve it when required) than to perform complex calculations for computing it from the given input. In other cases the opposite is true: the storage in long term memory is highly resource demanding but there is a fast and simple possibility of calculating the information explicitly. The required balancing between fossilization and restricted bidirectional processing is a highly complex, dynamic process which requires an advanced theory of cognitive resources in order to make precise predictions.

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