

Extending categorial grammar to phonology

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Abstract

What would be the implications of applying categorial grammar technology to phonological structure? We show how expressing phonological insights requires a few extensions into the formalism in order to be able to deal with autosegmentalism, with feature repulsion and with the interface with syntax (and possibly with semantics). It is argued that both our understanding of categorial grammar and phonology can profit from the confrontation.

Keywords: categorial grammar, phonology, autosegmentalism, formalism, representations

Theories of grammar, like all theories should be extendable to larger domains than to those for which they were originally designed. It is unlikely – though obviously not impossible – that human cognition applies completely different principles to the syntax of natural language than to other domains of cognition, in particular to other parts of grammar.

The extreme amount of ‘specialisation’ within linguistics however seems to block the study of such overlap in different domains. It seems to be a fact of life that linguists do not just specialise in relative small domains, but that these domains seem to be uniformly divided across the world: one identifies as a semanticist or as a phonologist. There is no linguist, as far as I know, who specialises e.g. in the study of representational primitives or linguistic computation across such domains. No doubt, a lot of insight is being lost because of this premature specialisation. Although I suppose I

am a victim to this same unfortunate trend, in this essay I try to explore how a framework developed mostly for syntax and semantics can be successfully applied also to phonology.

Phonology, unlike syntax and semantics, has not been widely studied within categorial grammar (Lambek 1958, Morrill 2010), for a variety of reasons, but probably mostly just because the intersection between people interested in the finer sound structure of language and people interested in the mathematical logic behind CG is very small. Some work has been done, e.g. by Moortgat (1988), Steedman (1996), on intonation and such 'higher order' phonology, and in particular Wheeler (1988) has done some attempts at describing 'standard' phonological phenomena within a categorial frame (see McGee Wood 2014 for an overview).

What is missing in all these previous attempts, as far as I can see, is going into the aspects of phonology that at first sight seem different. The concentration is on those aspects of phonology in which *constituency* seems to play an important role, such as the syllable, the stress foot, or higher order prosody. 'Lower order phonology' – basically anything involving the phonological feature – has not been discussed, in spite of its relevance to a large portion of the phonological literature. For instance, in Wheeler's work, subsegmental processes.

From the point of view of phonological theory, one reason for not being overly interested in categorial theories is that such theories are inherently lexicalist: differences between languages are reduced to differences between lexical items, i.e. between the primitives of those languages. There are on the other hands no differences in the computational system which is of a very simple, combinatory nature.

Lexicalist theories in this sense are very rare in the phonological world: they would entail that the primitives of the theory (phonemes, or features) differ in a significant way from one language to the next whereas the phonological rule system would not; and this would explain why one language has vowel harmony and another does not. The phonologists' inclination goes in the other direction,

towards making all differences between languages in the way in which primitives (features, all taken from a limited universal inventory) are combined.

In this contribution, I have tried to apply principles of categorial grammar to phonology, by way of an exercise. The question is whether by taking features as the primitive units, we can derive many known generalisations on human language phonology.

As I will demonstrate, the formalism may have to be extended in a variety of ways to explore phonological structure rather than the more familiar syntax and semantics. First, we know from phonology that these segments are not organized in a string, such as is usually assumed in categorial logic, but rather in autosegmental representations. Secondly, we need a formalism to account why certain features seem to repel each other rather than work as each others attractors. Thirdly, we need some formalism for accounting for what phonology can see of the other dimensions of linguistic structure. Altogether, this brief essay aims to show that, on the one hand, we can learn about categorial theories of grammar from applying them to slightly different empirical domains, and, secondly, that such an application itself can shed an interesting light on phonological problems.

1. A simple categorial system

A categorial grammar system can obviously be applied in a simple fashion to issues of phonotactics: we know that the building blocks of syllables can easily be described in terms that are very similar to those of syntax. It arguably is simpler in a number of ways (Van Oostendorp 2013). Most importantly, we see no (or very limited) recursive embedding of constituents within each other. There is recursion, but only in the form of iteration, e.g. a word consists of an unbounded number of syllables.

If we consider a (toy) language which only has CV syllables (Clements and Keyser 1983), the five vowels a, i, u and the two consonants t, m , we can obviously describe the internal structure of such a language in the following way, assuming that the atoms of phonological representation are ‘phonemes’, i.e. consonants and vowels (I use the notation by which A / B is a structure which is looking for a B on its right to form an A and $B \setminus A$ a structure looking for a B on its left with the same result).

$$(1) \quad \begin{array}{ll} a, i, u: & C \setminus \Sigma \\ t, m: & C \end{array}$$

Typically, we assume that the (universal) combinatorial grammar now contains the following rule:

Combinatorial Rule 1:

- (a) Two items of category A , $A \setminus B$ form an item of category B .
- (b) Two items of category B / A , A form an item of category B .

In most natural languages, things already become a bit more complicated because initial consonants can often be optional (Topintzi 2011). We need to introduce a mechanism for introducing such optionality. There are various possibilities for this; we need such a mechanism also to describe natural language syntax (e.g. for alternations such as ‘we are eating bread’ vs. ‘we are eating’). See e.g. Blom (2012) for an implementation in Abstract Categorical Grammar; Blom introduces the formalism of marking an argument as optional, which means that it can also be filled by an empty string. Such optional arguments are marked as $*$, and we thus get:

$$(2) \quad a, i, u: \quad C^* \setminus \Sigma$$

This also needs a new combinatorial rule:

Combinatorial Rule 2:

An item of category $A^* \setminus B$ or B / A^* can form an item of category B

Many languages have a more complicated syllable structure, allowing consonant clusters and closed syllables, for instance. One way of describing this is to assume that syllables have subconstituents: the onset (O) and the rhyme (R). Furthermore, we assume that each of these has can branch (binarily): an onset into two consonants, and a rhyme into a vowel and a consonant. The constituent structure of the English word *brick* is then:

(3) $((br)_O(i k)_R)_\Sigma$

Any language which allows for branching onsets and/or rhymes, also has simpler constituents. This means that branching is always optional, and this in turn means that we could enrich our notation for these languages with yet another optional constituent. In particular, in order to capture closed syllables, we can assign the following category to vowels:

(4) $a, i, u: (C^* \setminus \Sigma) / C^*$

Trying to extend this to the onset, a complication arises immediately, which is to so-called *sonority sequencing principle* (Parker 2011). Typically, or even universally, consonants can be put on a scale of so-called sonority, which is roughly as follows (there are proposals which have a much more fine-grained scale, and some languages have consonants that do not fit in an obvious way in this scale at all):

(5) *plosives* (p, t, k, b, d, g...) > *fricatives* (f, s, x, v,...) > *nasals* (m, n, ...) > *liquids* (l, r) > *glides* (j, w)

Sonority plays a role in various ways in phonotactics. Consonants in an onset are ordered according to it: a nasal can be the first consonant only when it is followed by a liquid or a glide, and the second consonant only when it is preceded by a plosive or a fricative. Still, these languages allow only binary constituents. Furthermore, in some languages, there is a minimal sonority distance. And finally, also the consonant in the rhyme can be subjected to sonority restrictions (which typically means that only consonants at the righthand side of the scale can close the syllable, with the cutoff point being set in a language-specific way).

It could be argued that sonority-based restrictions are not really phonological, and not the domain of grammar (Everett 2016). In principle, phonotactics would only need to specify that consonant clusters at the beginning of the word can consist of (at most) two consonants. Their order would be taken care of by extralinguistic factors, e.g. the fact that *rbick* is more difficult to produce and/or perceive than *brick*, makes it more difficult to transmit *rbick* type words, so that over the course of time they disappear from the language without grammar itself playing any role. However, there is ample experimental evidence that people seem to have *linguistic* knowledge of the difference between *brick* and *rbick*, even when they speak languages which allows neither cluster, or both (Berent 2013). It thus seems reasonable to ask of a grammatical theory to incorporate these observations.

Although it does not seem immediately straightforward how to do this, especially without assigning extremely complex formulas to every individual consonant, it does not seem impossible to do so in principle, as Wheeler (1981) has shown: we can divide the class of consonants into a number of subclasses, and assign a complex specification to each of them. Similarly, some problems posed by

individual languages or language families – in English, a triconsonantal cluster always start with *s*, as in *street* and *split*, and furthermore *s* seems the only segment that can violate sonority restrictions, witness also these words – can also be dealt with by assigning the right characterisation to such segments: it seems to me that we can characterise English *s* as follows, and get close to describing its behaviour in a way that is quite close to covering a lot of empirical ground:

(6) $s: C / C^*$

In most (and maybe all) languages, a word can consist of more than one syllable. Even in Chinese, syllables can be strung together to form a word. Furthermore, it has been observed that in all languages a possible word can always be parsed into a finite whole number of syllables, so that we can replace Σ in our formulas with the following (ω is a standard phonological notation for the word):

(7) $\Sigma: (\omega / \omega^*)$

(Wheeler 1981 gives a more refined idea about the phonological constituency within the word seen from the point of view of categorial grammar.) It is not unimportant to notice that in this notation ω will never occur on its own in the system in any language, but always in the configuration ω / ω , just like *C* will always appear in the configuration $(C^* \setminus \Sigma)$, describing a vowel.

The reason for this is that phonological structures are *tiered* (Goldsmith 1976): syllables are always sisters to other syllables and nothing else; onsets are always sisters to rhymes, and nothing else, just like rhymes are always sisters to onsets. At higher levels of phonological organization, words are sisters to words, etc. This is what was hinted at above, when we said that there is no embedding in

phonology: phonological constituents can always be divided into disjunctive equivalence classes, where they can only be sisters to elements of their own class.

For this reason, it seems advisable to keep Σ in our descriptions of consonants and vowels, and then add something like (7) as a separate notation. It is often believed that words are not just strings of syllables, but strings of feet, which themselves are binary units of syllables; but that just means a minimal extension of this idea.

All of this is obviously very sketchy, and quite far from giving a complete picture of the categorial system of any language beyond our toy language which has (strings of) CV syllables only.

However, none of the problems seem insurmountable. More interesting issues arise when we look at other territories of phonological representation. Such as the internal structure of the segment, to be discussed in the next section.

2. Autosegmental categorial grammar

Arguably one of the key discoveries of phonological theory of the twentieth century is that of the phonological feature: not phonemes, not consonants and vowels, are the atoms of phonological representation: they consist in turn of smaller units, phonological features.

There is no consensus about many aspects of these features. For instance, people do not agree on which labels can be used, whether features are unary, binary or even allow for multiple values, etc (see the various contributions to Volume 1 of Van Oostendorp et al. 2011). However, it seems fair to say that there still is consensus among formal phonologists that there is something smaller than this.

For our purposes, we have chosen to assume that features are unary (monovalent); I will use mnemonically relevant names as their labels, and thus assume that the consonant /t/ consists of the features Coronal and Plosive.

One task of phonological theory is to characterise what is a possible segment (that is the more common term within phonology for the object which is also called a phoneme) in a language. For instance, a Dutch consonant always has a manner component (which is roughly one of the points on the sonority scale above), and can have a number of other components such as a place of articulation, of which Coronal is one example (Labial and Velar are other examples). As a first attempt, we could describe this in the following way:

(8) (C / Place*) / Manner) [to be replaced in (9)]

One problem here is that a consonant should have a Manner feature, one out of {Plosive, Fricative, Sonorant, ...}, but not more than one. Another problem – and one on which we will concentrate here – is that the / operator suggests linear order, and such order is absent in the case of an individual consonant: the place is not produced *after* or *before* the consonant, but *while* saying the consonant; similarly, Place and Manner are not linearly ordered with respect to each other. We thus need another operator to represent this. Following Levelt & Van Oostendorp (2007) and Van 't Veer (2015) I will use \supset for this purpose, thus replacing (8) by (9):

(9) (C \supset Place*) \supset Manner)

Since we have introduced a new combinatorial symbol, we also need two new combinatorial rules:

Combinatorial Rule 3:

Two items of category B \supset A, A or A, B \supset A form an item of category B.

Combinatorial Rule 4:

An item of category B \supset A* forma an item of category B.

This simple device can already give interesting results. E.g., it can help us describe the process of vowel harmony, which is quite common in languages of the world. E.g. in Turkish the vowels in a single root are either both front or both back; combinations of the two are typically not allowed. In the following examples, {e, i, ö, ü} represent front vowels and {a, ı, o, u} back vowels.

(10) **Front-back harmony in Turkish roots (morphologically simplex words):**

- | | | | |
|----|--------|---------|-------------------------|
| a. | yanlış | ‘wrong’ | <i>*yanlış, *yenlış</i> |
| b. | yosun | ‘moss’ | <i>*yosün, *yösun</i> |
| c. | zengin | ‘rich’ | <i>*zengın, zangın</i> |
| d. | kömür | ‘coal’ | <i>*komür, *kömur</i> |

One way to see this within a categorial grammar is as a form of subcategorization: a Front vowel will combine only with a word in which the other vowels are also front. In terms of the notation already introduced:

- (11) $(\Sigma \supset \text{Front}): (\omega \supset \text{Front} / (\omega \supset \text{Front})^*)$ [to be revised in (14)]

However, this does not take into account one of the basic insights. The typical (autosegmental) analysis of this is that the feature Front is shared between two vowels in these roots: as soon as a vocalic feature Front shows up anywhere in the representation, it gets linked to *all* vocalic nodes which are present. In other words, the Turkish word for *rich* has the following subrepresentation:

- (12) z e n g i n
 \ /
 Front

There are various kinds of evidence for this representation. For instance, both vowels will undergo any change to Frontness in the same way, and also the consonants in between these two are phonetically realised as front (which is different in languages without harmony in which two front vowels in the same word each have their own Front specification):

(13) z e n g i n
 | |
 Front Front

A simple way to achieve the right effect would be to describe vowel harmony using an index, which denotes the identity of the same feature

(14) $(\Sigma \supset \text{Front}): (\omega \supset \text{Front}_i / (\omega \supset \text{Front}_i)^*)$

A Front syllable does not just look for syllables elsewhere in the word that are also Front, but to those that are linked to syllables with the *same* Front feature.

Being able to identify an individual instance of a feature is a crucial property of autosegmental theory, and even arguably its essence: it does not see features as being part of a segment, but as a segment in its own right. A consonant or a vowel does not ‘have’ features, but it is linked to features, which symmetrically are linked to it in return.

Another consequence of autosegmentalism is that features can be ‘floating’, which means they are not linked to any (other) part of the representation. As a consequence, autosegmental representations are sometimes seen as not necessarily connected graphs. They can be seen as collections of features, with the extra requirement that all features have to be satisfied:

(15) A (categorical) autosegmental representation is a set of features, where every $F \supset G$, F/G , $G \setminus F$ is connected to G in such a way that the representation can be resolved to F .

In other words, $F \supset G$, F/G and $G \setminus F$ can be seen as representations that are still missing a piece (still ‘needy’ in the words of Nevins 2010); and pieces may be disconnected, but they may not be missing. (We will discuss in section 4 how realistic autosegmental representations may not be disconnected after all; but also that (15) still holds in some way.)

Because of autosegmentalism, we thus do not just have configurations $A \supset B$, where A is a segment or a syllable, and B a feature, but also such structures where A is a feature and B something else: also features may demand to be connected to some other feature. This is necessary to describe a phenomenon that in phonology is known as ‘enhancement’: a feature is always accompanied by another feature (that enhances its effect). For instance, in many languages Round vowels are also necessarily Back, which means that in such languages we have the following structure of the feature Round:

(16) Round \supset Back

In this particular case, there is not necessarily an association line between the two features, which means that the interpretation of the combinatorial rule for $A \supset B$ may be something like this adjusted:

(17) $A \supset B$, $B \Rightarrow A$ *iff* there is an uninterrupted path between $A \supset B$ and B consisting of association relations and (at most) one segmental node.

The fact that $A \supset B$ needs to be added to our inventory of relations in order to describe autosegmental relations in phonology, does not mean that the use of these relations is restricted to that particular subfield of grammar. It has sometimes been argued that autosegmental relations also hold in syntax, and in particular the relation between syntactic heads and their constituting features is a topic that could be studied in more detail.

3. Feature repulsion

Another property that is unusual in the categorial literature, as far as I am aware, but that needs to be added at least for the purposes of phonology is that of feature repulsion. Sometimes specific features just cannot be combined. E.g. (Holland) Dutch has velar obstruents and voiced obstruents, but not voiced velar obstruents. This can be interpreted as a sign that the feature Velar repels the feature Voice: any representation in which these two are combined needs to be excluded. We can notate this as in (18), with the % sign as a negation:

(18) Velar $\supset\%$ Voice

The new combinatorial rule is:

Combinatorial Rule 5:

A representation with $A \supset\% B$, B is not well-formed if there is an uninterrupted path between $A \supset B$ and B consisting of association relations and (at most) one segmental node

Logically speaking, one could get something similar by a disjunction for the other place features.

Assuming for the sake of the argument that there are three of these (Labial, Coronal, Velar) we can also give the following partial specification for Labial and Coronal and say nothing about Velarity:

(19) Labial \supset Voice*

Coronal \supset Voice*

However, there is no reason to assume that in voiced labial or coronal segments, it is the place feature that optionally selects the voicing; rather, this seems a property of the segment. Although introduction of a negative operator such as /% does not seem to directly lead to a larger generative power, it seems therefore at least provide a more insightful way of expressing certain observations about how language works.

In the linear dimension, the use of negative operators is even clearer, for instance to describe the phenomenon which in the phonological literature is known as the *Obligatory Contour Principle* (OCP, Goldsmith 1976). This principle disallows two features which are the same to follow each other; in the original proposal, this concerned Tone, but OCP effects have been found for many other languages.

Here is a tonal example. As the following shows, the past tense marker *rá* and the first syllable of the verb for ‘to sew’, *báriirà*, both have a high tone in the Bantu language KiRundi, indicated by the acute accent (the grave accent denotes a low tone):

(20) *nà-rá-zì-báriirà*

I-PAST-them-sew

‘I was sewing them’

However, if we take away the low toned object marker, two high tones threaten to be adjacent to each other. As a result, the second low tone lowers (by a process known as Meeusen's rule):

(21) *nà-rá -bàrìrà*

I-PAST -sew

'I was sewing'

We cannot say that this is because a high tone demands a following low tone (H/L), because high tones can appear finally. What really seems to be going on here is that high tones cannot be followed by other high tones:

(22) H /% H (OCP, categorial style)

One obvious question to ask is of course, where does the initial low tone on *bàrìrà* in (21) come from? We have to assume that somehow we have a disjunctive choice: in the default case, the first vowel starts with a high tone, but if this is not possible, we can also opt to choose a low tone.

4. Interaction with morphosyntax

We are getting here on yet another territory that is familiar to phonologists, but does not play a role so much in syntax: that of making sure that elements which are present in the input also play a role in the output representation. It is quite generally accepted that phonological forms are not necessarily realized in exactly the same way as in which they are stored, for instance because there are phonological alternations: a form takes a different shape in one context to the next. (Dutch is a

language with final devoicing, which means that the singular word for ‘letter’, *brief* ends in an *f*, but its plural, *brieven* has a *v* in that same position. This means that either *f* was changed to *v*, or *v* to *f*, or something else entirely has changed into *f* in one position and into *v* in another position. In any case, we need some theory of what these possible changes (or relations between segments that are the same but occur in different positions) are. In semantics or morphosyntax such issues are not usually discussed within categorial grammar as whatever comes from the lexicon in those domains does not really seem to adapt itself to its environment.

As in related systems such as Declarative Phonology, it seems most sensible to assume that the relation between lexicon and phonological surface is monotonic: all lexical material is present in the surface form. Van Oostendorp (xx) proposes a theory for such adaptations, which is formalized in Optimality Theory (in particular in its Prince and Smolensky 1993/2004 version), but which can also be adapted to this kind of categorial system. The idea is that no lexical material is ever deleted, but it can under certain circumstances be left unparsed, i.e. it can be *not integrated* into the larger constituent structure; thereby it will be left uninterpreted. We have already seen above that it is an option of autosegmental theory that features can be left floating.

Van Oostendorp (xx) calls this a theory of morphological colours: every morpheme or other lexical item has its own ‘colour’, i.e. an identifying subscript. Every phonological feature which is part of that morpheme bears that colour, for instance in the form of a superscript. Thus, if we add together the English noun *kiss* and the plural morpheme /z/, we get the following:

$$(23) \quad k^i \ i^i \ s^i \ \Theta^0 \ z^j$$

The segments *k*, *i* and *s*, as well as all features attached to them carry index *i*, the segment *z* and its features, which belong to a different morpheme, the index *j* and the schwa, which is there for purely phonological reasons (viz. to avoid an OCP violation on the common features of *s* and *z*) carries no

index. The idea is that colourless material is always freely available in any phonological representation, but will only be integrated as a last resort: if we do not integrate it we get an ungrammatical representation.

Van Oostendorp shows that by referring to these colours, we can also understand many phenomena in the realm of morphosyntax-phonology interface, such as Derived Environment Effects and Cyclicity.

5. Conclusion

This paper gives obviously a rather sketchy view of the kinds of issues which need to be accommodated to devise a categorial system that can accommodate some of the key insights in phonological theory. It seems to me that we need at least:

1. optionality of argument satisfaction to account for the many cases where we can add 0 or 1 arguments (an onset of 1 or 2 consonants, a syllable with only a nucleus or also 1 onset, etc.) to a head, but not more.
2. a non-linear relation between features of the same segment
3. a way to refer to individual features
4. a way to describe repulsion of features next to attraction
5. morphological colours to describe epenthesis

These are not trivial additions, and their logical properties would obviously have to be studied further. Similarly, it should be tested empirically whether in this way it would be possible at all to build a phonological theory that is truly 'lexicalist' in the sense that it assumes that the combinatorial grammar is universal and therefore does not have to be learned. If successful, it may

give us some hope that the boundaries between current specializations will fall since the properties of such a system would obviously be of interest to semanticists and phonologists alike.

References

- Berent, I. 2013. *The Phonological Mind*. Cambridge: Cambridge University Press.
- Blom, Chris. 2012. Optional Arguments in Abstract Categorical Grammar. MSc Thesis, Utrecht University.
- Clements, George N. and Samuel J. Keyser. 1983. *CV phonology: A generative theory of the syllable*. Cambridge, MA: MIT Press. *Linguistic inquiry monographs* (No. 9).
- Coleman, John. *Phonological Representations: Their Names, Forms and Powers*. Cambridge: CUP, 2005.
- Everett, Daniel. 2016. An Evaluation of Universal Grammar and the Phonological Mind. *Frontiers in Psychology* <http://dx.doi.org/10.3389/fpsyg.2016.00015>
- Goldsmith, John. 1976. *Autosegmental Phonology*. PhD. Dissertation, MIT.
- Lambek, Joachim. 1958. The mathematics of sentence structure. *American Mathematical Monthly* 65: 154–170
- Levelt, Clara and Marc van Oostendorp (2007). Feature co-occurrence constraints in L1 acquisition. *Linguistics in the Netherlands* 2007, 162–172.
- McGee Wood, Mary. 2014. *Categorical grammars*. London: Routledge.
- Moortgat, Michael. 1988. *Categorical investigations*. Dordrecht: ICG.
- Morrill, Glynn. 2010. *Categorical Grammar: Logical Syntax, Semantics, and Processing*. Oxford University Press.
- Nevins, Andrew. 2010. *Locality in Vowel Harmony*. Cambridge, Mass.: MIT.

- van Oostendorp, Marc, 2007. Derived environment effects and consistency of exponence. In: Blaho, S., Bye, P., Krämer, M. (Eds.), *Freedom of Analysis?* Mouton de Gruyter Berlin/New York, pp. 123–148.
- Oostendorp, Marc van. 2013. σ strikes back: A defense of headedness and constituency in phonology. *The Linguistic Review*, 30(2), 347-371
- Oostendorp, Marc van, Colin Ewen, Beth Hume and Keren Rice (eds.) 2011. *The Blackwell Companion to Phonology*. Oxford: Blackwell,
- Parker, Steve. 2011. Sonority. In: Marc van Oostendorp, Colin Ewen, Beth Hume and Keren Rice (eds.) *The Blackwell Companion to Phonology*. Oxford: Blackwell, 2011. pp. 1233-1255.
- Scobbie, James M. 1997. *Autosegmental Representation in a Declarative Constraint-Based Framework*. New York: Garland.
- Topintzi, Nina. 2011. Onsets. In: Marc van Oostendorp, Colin Ewen, Beth Hume and Keren Rice (eds.) *The Blackwell Companion to Phonology*. Oxford: Blackwell, 2011. pp. 1021-1054.
- Steedman, Mark. 1996. *Surface Structure and Interpretation*. Cambridge, Mass: MIT Press.
- Van 't Veer, Marijn. 2015. *Building a Phonological Inventory - Feature Co-occurrence Constraints in Acquisition*. Utrecht: LOT.
- Wheeler, Deirdre. 1981. Aspects of a categorial theory of phonology. PhD Dissertation, University of Massachusetts at Amherst.
- Wheeler, Deirdre. 1988. Consequences of some categorically motivated phonological assumptions. In: Richard Oehrle, Emmon Bach and Deirdre Wheeler: *Categorial Grammars and Natural Language Structures*. Dordrecht: Reidel, 467-488.