Local Modeling and Syllabification

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1. DERIVATIONS

Some thirty years ago, a central question in phonological theory -- perhaps the central question -- concerned the nature of the relationship between the abstract, underlying, representations and the surface forms. It was a matter of great significance when it was established that the relationship was complex enough so that these two levels of representation could not be mediated by a single set of simultaneous rules -- nor could the whole story be told even when a single intermediate level of analysis (a "phonemic" level, in the event) was postulated.

In the years since, the notion of the derivation has been central to virtually all important work in phonology. The derivation provides a more complex and articulated relationship between the underlying and the surface forms, with phonological rules providing the links between successive intermediate stages of the derivation.

In recent work, we have been exploring an alternative to both the static neobloomfieldian view and the dynamic derivational view of generative grammar. The results we have obtained so far are promising, we believe, and it hardly needs to be emphasized that, if this avenue of research is correct, it will radically alter our conception of formal phonological analysis.

A new approach to phonological theory needs to be careful when it considers which questions it will address in its initial stages. In the best of cases, it will take on those areas of phonological research which we have some reason to believe are psychologically real and phonologically productive, and it should avoid those areas of phonology where the dividing line between productive phonology and arbitrary morphology is unclear. For this reason, we have chosen as our focus two areas of phonological analysis which are the most productive, which are among the best studied, and which in one form or other play a role in essentially every language of the world. These two areas are syllable structure and metrical (i.e., foot) structure. The latter we have dealt with elsewhere (Goldsmith 1989b), and we shall focus in this paper on syllable structure.

2. RULES AND REPRESENTATIONS

A fundamental distinction in work in phonological theory over the past
thirty years has been that between phonological rules and phonological representations (Anderson 1985 deals with the history of phonological theory in terms of this opposition). It has become quite apparent that developments in the art and articulation of phonological representations -- primarily autosegmental and metrical representations -- have led to a corresponding simplification in the rules attributed to each language. Some have drawn the conclusion that all rules can be dispensed with entirely; others (including ourselves in the past) have taken the view that the development of geometrical models led to a qualitative simplification of the rule formalisms, to the point where geometrical simplicity becomes the goal that guides the development of phonological theory.

Our view today is somewhat different; we propose a synthesis of rules and representations, in a fashion that is similar to (and largely inspired by) recent work in connectionist modeling. We aim to provide formal models (and in general, computer-implemented models) which have, in common with connectionist modeling, an internal dynamic of their own. Current theories of phonology contain within them representations which are -- implicitly, to be sure -- written on a mental blackboard in the vocabulary of the theory. They are modified, if at all, by rules which add, delete, or modify parts of the representation in an explicit fashion. In our scheme, however, a given word (for example) is represented by a set of units, each assigned an activation level between -10 and +10. These units represent, in general, the features which comprise the segment, as well as playing other phonological roles. But because the units form a network, and because activation spreads from one unit to another in accord with the structure of the network, our networks always, and automatically, have the property that when we "input" a representation to them, they quickly move out of that state into some other "nearby" (i.e., similar) state, one which we may say that they prefer. This automatic movement, as we shall see, is the essence of our model, and corresponds to the effects of phonological rules; how this might work, in a particular case, will become clearer as we consider our first example (and see Goldsmith 1989b for another example of the model).

3. SONORITY

The third phonological concept that informs our model in a central way is the sonority hierarchy, and the curious and uncomfortable way it has fit (or been forced to fit) into generative conceptions of syllabification.1 It will be helpful for us to recall that the sonority hierarchy is a statement of the relative inclination of the segments of a language to be the nucleus of their particular syllable. Segments that are highly sonorous -- vowels, in particular -- are strongly inclined to be found in syllable nuclear position (meaning that in some languages, they always appear in nuclear position, while in others they can be "forced" from nuclear position only by competition among them for appearance in that position -- something that is more sonorous can edge out appearing in syllable nuclei, typically can frequently cannot appear in some languages, even nothing that is more so neighborhood.

Summarizing the values are assigned to them that "peaks", or local maxima in the nucleus of the syllable segment whose sonority exceeds that of its neighbors). This gene the "Sonority Principle" -- syllable nuclei, and second higher in sonority than hand neighbors (their coarticulation.

Such traditional view of generative phonology -- is not directly expresses traditional generative grammar, the language in which we are reared. Inherent sonority is greater in such a case, we need to "all the more" language assigns syllable structure, as more difficult matters.

But if we must fix a predetermined set of sonority values that are higher than their neighbors', we can do so by setting up a rule scheme that respects sonority hierarchy; they will be respected by our system. Thus, the first rule picks the nucleus of the syllable and marks it as the highest sonority of all syllable nuclei. The next rule picks the next highest sonority nuclei and marks it as the highest sonority of all syllable nuclei. This rule ordering, a part of our current approach, works well.
sonorous can edge out something that is less sonorous in the competition for appearing in syllable nucleus position. Similarly, low sonority items, such as obstruents, typically cannot appear in nuclear position in most languages, and frequently cannot appear in coda position either; they must appear in onset position. In some languages, even obstruents can appear in nuclear position, but again only if nothing that is more sonorous is available in the nearby phonological neighborhood.

Summarizing the big picture, then, as far as sonority goes: when sonority values are assigned to the segments of a representation, it is by and large the case that "peaks", or local maxima, of sonority are the segments that are assigned to be the nucleus of the syllable (by "peak" or "local maximum", we mean simply a segment whose sonority is higher than that of both its left- and right-hand neighbors). This generalization, which is roughly what Clements 1987 refers to as the "Sonority Principle", has two sides to it: typically all peaks of sonority are syllable nuclei, and second, all syllable nuclei are sonority peaks, and thus are higher in sonority than their left-hand neighbors (i.e., their onsets) or their right-hand neighbors (their codas, if they have codas).

Such traditional generalizations are difficult to capture from the point of view of generative phonology. The notion of "peak" -- of finding a local maximum -- is not directly expressible with the conceptual apparatus that is provided in traditional generative grammar. Initial syllabification will typically be easy in a language in which we can pick out a special class of segments as being those whose inherent sonority is great enough to guarantee it pride of place as a syllable nucleus. In such a case, we need simply say that the core syllabification procedure of the language assigns syllable nucleus position to a [+vocalic] segment, and move on to more difficult matters.

But if we must look carefully to assign syllabification not simply to any predetermined set of segments, but to those segments whose sonority is relatively higher than their neighbors, things are not so simple. Dell and Elmedlaoui 1985, a thorough and insightful account to which we will return, pick out sonority maxima by setting up a rule schema with eight subrules to it, one for each step on the sonority hierarchy; they then apply these rules in order of decreasing sonority. Thus, the first rule picks out all a's, and marks them as the nucleus of the syllable, and marks the previous segment as a syllable onset, no longer fit to serve as a syllable nucleus. The next rule applies to the output of the first, and marks as syllable nuclei all i's or u's except those that became onset segments by the previous rule application. Segments immediately before these new i, u syllable nuclei are also now marked as syllable onsets, and then the same procedure applies to mark liquids as syllable nuclei, unless they stand immediately to the left of an a, i, or u, which will already have been marked as a syllable nucleus. And so forth. Such an approach works, but puts the burden of explaining sonority relations on rule ordering, a part of our theory that is certainly guaranteed to explain nothing at all. In addition, this approach postulates a set of eight rules (the subrules forming
the rule schema) which apply iteratively from left to right across the utterance, one at a time. There is surely something suspect regarding the psychological plausibility of a model in which an utterance must be scanned eight times from beginning to end before it is properly structured. We will return to the case of Berber in just a moment.

4. THE NATURE OF OUR MODEL

In this brief paper, we can do little more than sketch two simple aspects of the kind of model that we have developed, a model which incorporates the theoretical goals which we have outlined above. Our basic conception of the phonological representation is one in which there is a central skeletal tier consisting of a linear string of units, each of which will develop an activation level which is derived from two factors. First, each skeletal unit is associated to the autosegments which define it phonologically, and from these autosegmental (or featural) specifications, it receives an activation that essentially corresponds to its segmental sonority. We will refer to this as the inherent sonority of the segment.

So far, nothing new. We now add a connectionist twist to the model: each unit in the skeletal tier communicates, quantitatively, with its left- and right-hand neighbors, passing activation (or, for the linguist, sonority) back and forth, according to a simple algorithm, such as that given in (2), where 't' represents 'time'. After a certain short period, the system settles into equilibrium, a point at which all passing of activation into a unit is balanced by passing of activation out of that unit. The activation level of each unit at that equilibrium point is what we may now refer to as the derived sonority of the segment, and it represents, as a moment's thought will clarify, a statement of the sonority of the segment when it is found in the particular phonological context in question.

\[
\begin{align*}
&\text{(2)} & a_{t+1} = 0 & \text{where } a_t \text{ represents}\nonumber \\
&\text{Our primary hypothesis}\nonumber \\
&\text{(3)} & \text{When the system settles at equilibrium,}\nonumber \\
&\text{a. Syllable edges a,} & & \\
&\text{b. A segment's sonority is derived from its features}\nonumber \\
&\text{c. The primary algorithm is:} & & \\
&\text{In Goldsmith 1986 and in particular}\nonumber \\
&\text{Ultimately, our main contribution is to conceptualize the sonority of a unit as a combination of the sonority of its neighbors and the sonority of the segment itself.}\nonumber \\
&\text{5. SYLLABICATION}\nonumber \\
&\text{One of the most important issues in phonology is the way in which syllabic structure is organized. We have seen that the sonority of a unit is a function of its features and its position relative to other units. This leads to the prediction that units with high sonority will tend to be syllabic nuclei, while units with low sonority will tend to be syllabic coda.}\nonumber \\
&\text{Berber}\nonumber \\
&\text{and we are pleased to report that our\nonumber }
\end{align*}
\]
where $a_i$ represents the activation level of the $i$th unit.

Our primary hypothesis is this:

(3) When the appropriate activation passing algorithm is selected,
    
    a. Syllabification is determined (and indeed, defined) directly by the 
       derived sonority, in that:
       
       i. maxima of derived sonority define syllable nuclei (peaks), and 
       ii. minima of derived sonority define (the beginning of) 
           syllable onsets.

    b. A segment which is a maximum or minimum (nucleus or onset) will 
       always be (autoformatively) licensed. A segment whose (derived) 
       sonority is neither a local maximum nor minimum will be licensed 
       (i.e., may be pronounced) just in case its derived sonority is above a 
       (language-specific) threshold $T$. (Space limitations prevent further 
       discussion of this proposal here; see Larson and Goldsmith 1990 for 
       details.)

    c. The primary language-specific parameters that determine the overall 
       syllable structure of a language are $\alpha$, $\beta$ in (2) and the threshold $T$ 
       in (b) above.

In Goldsmith 1989b, we offered a treatment of basic properties of the metrical grid, 
and in particular of alternating stress in Indonesian, with the same formal model. 
Ultimately, our model dispenses with syllabification entirely, replacing it 
conceptually with the rises and falls in derived sonority, though the syllable 
divisions and nuclei of traditional syllables are reconstructed out of the minima and 
maxima of the derived sonority waves.

5. SYLLABIFICATION IN BERBER

One of the original stimuli for the development of this model was the well-
known paper by Dell and Elmedlaoui 1985 concerning syllabification in Imdlwan 
Tashlihyt Berber, which we shall henceforth in this paper refer to simply as Berber, 
and we are pleased to acknowledge the important influence of this paper on our 
research. Berber is a language in which a simple division of the segmental...
inventory into vowels and consonants cannot, apparently, be motivated. Rather, the segments are organized according to a sonority hierarchy of a familiar sort:

(4) low vowel a 8  
high vocoids i, u 7  
liquids 5  
nasals 4  
voiced fricatives 3  
voiceless fricatives 2  
voiced stops 1  
voiceless stops 0

In the discussion that follows, we shall ignore the special syllabification properties of phrase-final syllables (which allow for quite complex codas or appendices), and shall discuss only phrase-medial syllabification. The first principle of syllabification -- first in that it is the most striking, not in that it is the absolute guiding principle -- is that syllable nuclei and local maxima (or peaks) of sonority, by and large, coincide, i.e., the "Sonority Principle" alluded to above. Several ways of establishing a formal device that locates local maxima could be imagined; but Berber is not quite that simple in any event. Dell and Elmedlaoui offer a large number of examples, including the forms in (5), with two forms of the paradigm for a number of verbs, where the Sonority Principle does hold straightforwardly.

(5) 2nd person singular perfective 3rd person feminine singular w/ 3rd masc. sg. object

tRgLt tRglAs "lock"  
tSkRt tSkrAs "do"  
tZdMt tZdmAs "gather wood"

3rd person masc. sg. perfective 3rd feminine singular
ILDf tLDf "pull"  
IrBAl tRbAl "carry on one's back"  
Istf tStf "select"

The first noticeable departure from the principle that syllable nuclei coincide with sonority peaks involve forms like tLwAl (a Berber place name), a form in which the inherent sonority of L is less than the inherent sonority of w (i.e., of u); nonetheless, L is a syllable nucleus. (We follow here Dell and Elmedlaoui's convention that a capitalized letter indicates a syllable nucleus.) The reason is, in a sense, obvious; the following a demands to be a syllable nucleus -- no one and
nothing can get in its way; but once that is established, it follows that the preceding u will be the onset for that syllable (i.e., creating the syllable wa), and the preceding i is free to be the nucleus of a syllable, no longer facing serious competition from the now-depleted sonority of the following u (turned onset w).

We have developed several related models which address this interaction, as we noted above. In general, these models contain a string of units -- a skeletal tier -- each of which is assigned an activation level (a number between 0 and 10) on the basis of the segment that is assigned to that skeletal position -- in effect, the inherent sonority of the segment at that position. Each unit has connections to the units neighboring on the left and on the right. We shall adopt, for purposes of concreteness, a set of values for inherent sonority as given in (4), based on a natural set of assumptions.4

If α, β are zero, and we allow our system to pick out peaks of sonority and assign them the status as head or nucleus of their syllable, then our system will be in essence a "sonority principle" device, and nothing more.

If, however, we let α, β be larger than 0 (though less than 1), we develop a system that expresses a competition between neighbors. Let us consider, for example, the derived activation, or derived sonority for the word LwAt, for several values of (a,b), given in (6). Similar is the form in (7) /t/-Izrul-In/ tlzRwAliN "those (fem.) from Tazrwal", where the syllable peaks are i, r, a, i successively, even though the u is more sonorous than the preceding r. (8) shows the analysis of haulin "he made them (masc.) plentiful", which is syllabified I hA wL tN.

\[
\begin{array}{cccccccc}
\alpha,\beta & t & l & u & a & t \\
0,0 & 0 & 5 & 7 & 8 & 0 \\
3,0 & -1.09 & 3.62 & 4.60 & 8.0 & 0.0 \\
5,0 & -1.75 & 3.50 & 3.00 & 8.00 & 0.00 \\
5,.15 & -2.11 & 4.22 & 2.19 & 8.35 & -1.36 \\
6,.10 & -2.60 & 4.34 & 1.54 & 8.38 & -.89 \\
\end{array}
\]

(7) (α,β)=(0.6, 0.1)

<table>
<thead>
<tr>
<th></th>
<th>i</th>
<th>z</th>
<th>r</th>
<th>w</th>
<th>a</th>
<th>l</th>
<th>i</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>7</td>
<td>3</td>
<td>5</td>
<td>7</td>
<td>8</td>
<td>5</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>-4.39</td>
<td>7.31</td>
<td>0.21</td>
<td>3.43</td>
<td>2.58</td>
<td>6.80</td>
<td>1.57</td>
<td>4.58</td>
<td>3.77</td>
</tr>
</tbody>
</table>

(8) (α,β)=(0.6, 0.1)

<table>
<thead>
<tr>
<th></th>
<th>i</th>
<th>h</th>
<th>a</th>
<th>u</th>
<th>l</th>
<th>t</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>2</td>
<td>8</td>
<td>7</td>
<td>5</td>
<td>0</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>8.85</td>
<td>-3.08</td>
<td>7.00</td>
<td>2.19</td>
<td>6.86</td>
<td>-3.46</td>
<td>4.62</td>
<td></td>
</tr>
</tbody>
</table>
As we see, a suitable choice of non-zero $\alpha$, $\beta$ leads the system to a state -- an activation state -- where the local peak is not what we might have expected purely on the basis of the inherent sonority of the segments involved, and in fact, we find that the inherent sonority of the $u$ of *lwAt* is -- correctly, in the event -- diminished by the sonority of the righthand $\alpha$ to the extent that the correct pattern of syllabification is identified by selecting local maxima of derived sonority; the $I$ is more active (i.e., more sonorous) than the following $u$.

Where do these choices of $\alpha$ and $\beta$ come from? We have noted that in describing this model to our fellow linguists, this question is always posed with some puzzlement. The choice of a pair of $\alpha$, $\beta$ is a choice of a language-specific grammar (or a part of a grammar, rather). The choice is thus made on empirical grounds, by the linguist just as by the language learner. It is striking that for a large class of cases, any choice of $\alpha$, $\beta$ over quite a wide range give the correct results, and we may assume, if we choose, that the initial setting of $(\alpha, \beta)$ is $(5,0)$, for example, or any value near that (the same observation is made in Goldsmith 1989b with regard to the corresponding local model of the metrical grid). The cases where $(\alpha, \beta)=(0,0)$ works are the cases where the simple Sonority Principle holds; for all others, some departure from this setting is necessary, and the degree of departure will be determined by the data of the language.

6. Conclusion

We conceive of our program in the terms of established linguistic theory, we believe that the techniques and the insights of connectionist modeling do not in any significant way undercut the progress made in phonological theory over the past several decades. We are currently exploring several slightly different models regarding the fundamental architecture of the connections among the basic units. The differences among these models involve different assumptions regarding the number of tiers of units, and the precise character of the connections among these tiers. We take each of these hypotheses to be explicit hypotheses regarding Universal Grammar, or that aspect of it that concerns phonology.

Each model contains within it a number of parameters that specify the weights on the connections between the individual units, such as the $\alpha$ and $\beta$ that we have discussed in connection with Berber. These weights determine how activation is spread among the units, and correspond within our model to what are normally considered to be the phonological rules of the language.

Finally, each state of the device consists of the specification of the activation of each individual unit within it (in a word, the activation vector of the model); such a state is our way of talking about a representation of a given word or expression.

NOTES
1 We have been...
2 In many lang...
3 The issue is a...
In schematic form, then:

<table>
<thead>
<tr>
<th>Architecture of the network</th>
<th>universal grammar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pattern of connection weights</td>
<td>language-specific grammar</td>
</tr>
<tr>
<td>Activation vector (i.e., activation of all units)</td>
<td>representation of a specific expression</td>
</tr>
</tbody>
</table>

We have considered a number of proposals in this paper which are logically independent: the treatment of sonority as a scalar dimension; the proposition that the sonority of a segment is context-dependent; the notion that the recalibration of context-sensitive, or derived, sonority is a language-particular arithmetic notion based on language-particular parameters ($\alpha, \beta$) and a simple, local calculation; and finally, that the phonological rules (of a particular level; see Goldsmith 1989a, 1990, or harmonic phonology) along with their concomitant ordering and intermediate representations can be replaced by a dynamic system in which a network determines maximal satisfaction of phonological constraints. Most of these proposals, again, are logically independent, but together they form an interesting and appealing program for research, some early results of which we have described here.

NOTES

1 We have been influenced considerably here by the discussion in Clements 1987. As Clements notes, significant debt is due to work by Sievers 1893, Jespersen 1904, Vennemann 1972, Hooper [Bybee] 1976, Foley 1977, Steriade 1982, and others.

2 In many languages, a threshold must be established as well for nuclear segments (that is, sonority must be above the threshold to be licensed at a sonority maximum). In view of the fact that Berber does not have this condition, we leave this aside here.

3 The issue is a good deal more complex than it might seem at first blush. Traditional phonological representations and our own quasi-connectionist models share in common the characteristic of treating time as if it were simply space: that is, the inherent dynamic of time -- the fact that phonological representations are read, from left to right, in time -- plays no role at all in any of these models. This may be an error; if we did consider the representations as being fed into a device that analyzed them temporally (like the head of a tape recorder, or a Turing machine), then it would be a simple matter to devise a machine that detected local maxima. If we restrict our attention to the same type of local models considered in the text, then local maxima can be determined in various ways, none obviously better than the others.
The numbers are given below. In terms familiar in connectionist modeling, the sonority is derived by taking the dot product of two vectors: the vector specifying the segment in question (i.e., its specification in binary features, where +Feature is represented as the coordinate "1", and the -Feature is represented as "0") and a vector indicating the relative contribution of the features toward this abstract phonological characteristic that we call phonological sonority, which in this case is the vector \( W = (1,2,5,-1,2,1) \). (We do not assume that sonorants are considered voiced at this level of representation though the point is irrelevant to the larger issues surrounding the model.).

(i)

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>+voice</td>
<td>1</td>
</tr>
<tr>
<td>+continuant</td>
<td>2</td>
</tr>
<tr>
<td>+sonorant</td>
<td>5</td>
</tr>
<tr>
<td>+nasal</td>
<td>-1</td>
</tr>
<tr>
<td>+vocalic</td>
<td>2</td>
</tr>
<tr>
<td>+low</td>
<td>1</td>
</tr>
</tbody>
</table>

(ii) vectors (voice, continuant, sonorant, nasal, vocalic, low)

<table>
<thead>
<tr>
<th>Segments</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>a ((0,0,1,0,1,1))</td>
<td>a.W=8</td>
</tr>
<tr>
<td>i ((0,0,1,0,1,0))</td>
<td>i.W=7</td>
</tr>
<tr>
<td>l ((0,0,1,1,0,0))</td>
<td>l.W=5</td>
</tr>
<tr>
<td>n ((0,0,1,1,1,0))</td>
<td>n.W=4</td>
</tr>
<tr>
<td>z ((1,1,0,0,0,0))</td>
<td>z.W=3</td>
</tr>
<tr>
<td>s ((1,1,0,0,0,0))</td>
<td>s.W=2</td>
</tr>
<tr>
<td>b ((1,0,0,0,0,0))</td>
<td>b.W=1</td>
</tr>
<tr>
<td>p ((0,0,0,0,0,0))</td>
<td>p.W=0</td>
</tr>
</tbody>
</table>

Thus the specification of the vector \( W \) is our formal way of specifying the sonority hierarchy, put another way, the sonority hierarchy is the result of the varying values obtained by projecting the vectors specifying the segments of the language onto the language-specific sonority vector \( W \). (Clements 1987 accomplishes something similar (p. 11, (5)), using an arithmetic of features that counts certain feature specifications, without the kind of weighting implicit in the vector \( W \) given here.)

The question naturally arises as to what determines \( W \), or rather, what the nature is of the process by which \( W \) is determined in language-particular fashion. This question arises for any phonological theory incorporating a sonority hierarchy: where does it come from?

In work that we have done since the conference presentation of this paper, we have been able to provide a more explicit and quantitative answer to this question than was available in the spring of 1990. We have developed a learning apparatus which notation, tagged sonority. In effect, learner, at least facing the child function, but no least. We initial feature in a pure following way. effect, by perfor segment in the same device expects it; however, the de fact the segment feature which w segment is in feature that is th This leads in an coefficients for Berber:

+voice
+continuant
+nasal
+vocalic
+low
+labial
+anterior
+coronal
+back

These results ar
apparatus which accepts as its input sequences of segments represented in feature notation, tagged with an indication as to which segments are the superficial peaks of sonority. In effect, we take these facts to be directly accessible to the language learner, at least at the point where syllable structure is the current learning task facing the child. We endow the apparatus with a simple and classical learning function, but no initial knowledge -- no accurate or correct initial knowledge, at least. We initialize the device with a set of coefficients for the sonority of each feature in a purely random fashion, and then permit learning to occur in the following way. The device will calculate sonority peaks as indicated above (in effect, by performing the inner product of its present sonority vector with each segment in the string, and identifying local maxima). If a local maximum that the device expects corresponds in fact to a local maximum, no learning takes place. If, however, the device calculates that a given segment should be a maximum, but in fact the segment is not, the device deduces a fixed proportion of the weight of each feature which was turned on in the segment in question. Similarly, if a given segment is in fact a sonority peak, but the current sonority vector in use by the device fails to identify it as a local peak, then the sonority coefficients for each feature that is turned on in that segment is increased by the same fixed proportion. This leads in an extraordinarily rapid manner to a calculation of the sonority coefficients for a given language. The following are the coefficients calculated for Berber:

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>+voice</td>
<td>.07</td>
</tr>
<tr>
<td>+continuant</td>
<td>.24</td>
</tr>
<tr>
<td>+nasal</td>
<td>.47</td>
</tr>
<tr>
<td>+vocalic</td>
<td>.92</td>
</tr>
<tr>
<td>+low</td>
<td>.29</td>
</tr>
<tr>
<td>+labial</td>
<td>.35</td>
</tr>
<tr>
<td>+anterior</td>
<td>.15</td>
</tr>
<tr>
<td>+coronal</td>
<td>.31</td>
</tr>
<tr>
<td>+back</td>
<td>.60</td>
</tr>
<tr>
<td>+strident</td>
<td>.19</td>
</tr>
<tr>
<td>+rhotic</td>
<td>.65</td>
</tr>
<tr>
<td>+lateral</td>
<td>.56</td>
</tr>
<tr>
<td>+high</td>
<td>.54</td>
</tr>
<tr>
<td>+back</td>
<td>.64</td>
</tr>
<tr>
<td>+round</td>
<td>-.35</td>
</tr>
<tr>
<td>alpha</td>
<td>-.35</td>
</tr>
<tr>
<td>beta</td>
<td>-.20</td>
</tr>
</tbody>
</table>

These results are discussed in greater detail in papers currently in progress.

In one extremely important respect, our work departs from a fundamental assumption (we are tempted to call it a philosophical assumption) that has informed most work in connectionism. We do not see language learning as being largely a matter of extraction of statistical effects in the data presented to the learner, although as note 4 above suggests, such notions may be helpful in determining some of the language-particular properties of a grammar. Much of what is of interest to the linguist, we are convinced, devolves from the fundamental architecture of the
device which we are exploring, and in this respect our research remains within the familiar tradition of recent grammatical theory.

REFERENCES


