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# Local Modelling in Phonology

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### Introduction

Recent work in connectionist modelling suggests the possibility of formal models of phonological representation which will offer deeper explanations of basic phonological properties than our current models allow us. The present paper is an initial exploration of certain linguistic problems from this newer perspective.[1] It is also, as I shall explain in the final section, an effort to produce a formal phonological grammar that is neither static nor derivational – a model that is not a hybrid of the two but, in fact, different from both.

Our goal in these explorations is the traditional goal in phonological work: the development of a formal model that allows for a simple and direct account of facts within a specific language, set within the framework of an approach which allows for the statement of the principles found in other languages and yet which allows for as few unobserved sorts of principles as possible. It is of some importance for us to observe that the goals we set are those of the traditional linguist, and not – at least not directly – those of other connectionist modellers, whose goals may be informed by other theoretical questions, including (but not limited to) the issues of learnability, the relevance of particular connectionist learning techniques (such as back-propagation, for example), the significance of a memory structure that is content-addressable, or the importance of prototype effects.

None of these play a central role in the present discussion, and to that extent we may recognize that the present paper may be of more interest to the linguist than to the connectionist.[2] Nonetheless, we approach one of the best studied of the higher level cognitive functions – language, and, in particular, phonology – and anything we can learn from this subject should be of general, and perhaps particular, interest to students of mental modelling.

## Principles Informing Our Approach

The properties that characterize the models we will explore are the following:

(1) *Gradience:* representations consist of a set of units, each of which is assigned an activation level, a variable that can range over all values within a real interval (in most cases, the interval being all real numbers, with a practical limitation keeping them not far from the internal (-1,1)).

(2) *Categorical effects out of gradience:* continuous-valued variables may be used to model categorical effects, either by seeking maxima and minima or by use of threshold techniques. That is, a linguistic effect may be reported as reflecting a variable (e.g., stress) which takes on only a small number of values (typically two, in which case the values may be referred to as +/-). A continuous-valued variable V within the model may be reduced to a 'categorical' variable C by establishing thresholds so that a value of V above the threshold corresponds to + C, and a value below the threshold corresponds to - C. Subthreshold effects within the variable V, however, will typically continue to play an important role in a fashion which the categorical model, induced from the continuous-valued model, cannot directly simulate. More frequently, we will look not for thresholds as such, but, rather, turning points – maxima and minima – in the curves that are developed.

(3) *Local computation:* the effects with which we will be concerned will all be the result of establishing simple arithmetic relations for the activation of neighbouring units.

(4) *Homogeneity:* we will consider a number of parameters that govern the way in which units (corresponding at times to segments and at times to syllables) affect the activation level of their neighbours (our $\alpha$, $\beta$, etc., below). We will assume that these parameters are uniform within a given language and may not vary from place to place within a word. This assumption has no natural grounding in current connectionist work but seems extremely natural (indeed, unavoidable) from the point of view of the linguist.

(5) *No hidden representations:* all linguistically relevant generalizations are realized within the model as connectionist effects operating simultaneously and interacting symmetrically with each other. None can be said to apply 'before' or 'after' another.

## Some Specifics of Our Proposal

The central suggestions of this paper are that:

(A) First, the organizing principles of the metrical grid, which creates feet from syllables, and the organizing principle on the skeletal tier, which creates syllables from segments on that tier, are in essence the same, though they differ in the setting of particular arithmetic parameters;

(B) Second, the metrical grid and the skeletal tier should each be modelled as a linear sequence of units in which each unit is assigned a real number for an activation value and in which each unit directly affects its (left- and right-hand) neighbours;

(C) Third, the structure we observe on the metrical grid (head and non-head positions in feet) and on the skeletal tier (onset, nucleus, and coda assignment) is the result of finding peaks and troughs and of imposing thresholds on the activation values of the elements on the grid and skeleton.

## The Metrical Grid

The metrical grid is a type of phonological representation designed to express naturally the properties of stress and accent systems observed in natural languages.[3] It is an object, as in Figure 7.1, that consists, first,

```
        x                   Row 2
  x   x                     Row 1
  x x x   x                 Row 0
  Alabama
```

Figure 7.1

of a bottom row of positions (Row 0), each of which represents (or corresponds to, or is associated with) a syllable. Above some of these Row 0 elements may be found a Row 1 element; these syllables are those that are stressed (i.e., Row 1 markings represent simple stress). Row 0 elements with no Row 1 marking over them are unstressed. A Row 2 element, in turn, may be found on top of some of the Row 1 elements (though not over any position where a Row 1 element is not found). Such syllables, which have a Row 0, 1, and 2 element above them, are taken to bear word-level primary stress and so forth: the higher the column of markings over a Row 0 element the higher the degree of its stress. While it is nowhere written in gilt letters, it is nonetheless uncontroversial to suggest that the two fundamental properties of the

metrical grid are, first, its inherent avoidance of Stress Clash, and, second, its tendency towards Perfect Grid. Stress Clash refers to the congeries of ways in which stress on consecutive syllables is avoided either by blocking a rule (such as Perfect Grid or the End Rule) from applying if that would create a stress clash or by triggering a rule of stress movement or deletion in case stress clash has arisen. Perfect Grid is the name assigned (by Prince 1982) to the rule that assigns stress to alternate syllables radiating outward (left and right) from a syllable already assigned stress. These two properties are neither explained nor explainable within grid theory nor are they related to one another within grid theory. This is, we suggest, an unsatisfactory place to leave the matter.

A local network of the sort we outlined above can shed light on this problem. We may consider a model which consists of a sequence of units, each of which conceptually correspond to a Row 0 element in the familiar grid (i.e., a syllable[4]). Units whose activations are local maxima, that is, whose activation is greater than either of its neighbours', are phonologically stressed.

Each unit inhibits its two neighbours, though not in quite identical fashion. If we say generally that the activation level of the ith element is $x_i$, then we will say that the ith element sends an inhibitory signal of strength $\alpha.x_i$ to the preceding element (i.e., to the $i$-1th element), and it sends an inhibitory signal of strength $\beta.x_i$ to the element on the right (i.e., the $i$+1th element), as suggested in Figure 7.2; the inhibitory relations there should be understood as being established between all pairs of neighbours. This is more explicitly given in Example 7.1, where the superscript $t$ marks time, that is, the timing of the iterative recomputations.[5]



( internal activations)
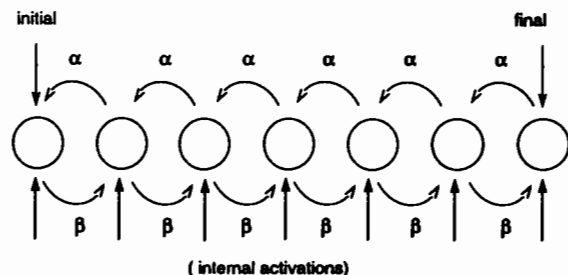
Figure 7.2: Dynamic computational network

$$x_i^{t+1} = K(i) + \alpha.x_{i+1}^t + \beta.x_{i-1}^t \tag{1}$$

If none of the elements are activated, then the elements of the grid are all at zero level, which provides no information about stress. However, from a phonologist's point of view, the activation of a grid element is the composition of three factors:

(1) positionally-defined stress, as when, for example, the first or the penultimate syllable of a word is stressed by a general rule of the language; the amount of positional activation may be different for these two positions.

(2) the effects of Perfect Grid, i.e., the local effects of the stress of neighbouring elements; and

(3) inherent stress arising out of quantity-sensitivity, i.e., language-specific principles by which syllables with a particular internal structure are ipso facto stressed (typically, those syllables with a long vowel and often, also, those which end with a consonant) regardless of where they appear in a word.[6]

We shall not discuss the effects of quantity-sensitivity in this paper, leaving the matter to the longer treatment that it deserves. The effects of Perfect Grid may be modelled as above, with the leftward and rightward inhibitory effects indicated in Figure 7.2. In general, it is helpful to distinguish between inherent activation of an element and derived activation, where the derived activation is that produced by the effects of lateral inhibition, and inherent activation is due to the effects of positionally-defined stress or of quantity-sensitivity. Let us consider the matter of positionally-defined stress in a bit more detail.

Consider the case of a language where the first syllable is stressed. We may indicate this with a function $K$ (mnemonically, from 'characteristic function'), defined on the indices of the grid elements, in such a fashion that $K(1)=1.0$ (i.e., the first element is activated) and $K(i)=0$ for all $i$ other than 1.

In such a scheme, if $\alpha$ and $\beta$ are both negative (and we assume, in this paper, that $\alpha$ and $\beta$ are both between -1.0 and 0.0), then the positive activation of $x_1$ will give rise to a (negative) activation of $x_2$ equal to $\beta$; this, in turn, will give rise to a (positive activation) of $x_3$ of $\beta^2$. The negative activation of $x_2$ not only leads to a positive activation of $x_3$; it also, in turn, leads to a higher activation of $x_1$ through what we might call the

$\alpha$=-0.2,   $\beta$=-0.7.
Syllable Number:

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| 1 | | | | |
| 1 | -.70 | | | |
| 1.14 | -.70 | .49 | | |
| 1.14 | -.90 | .49 | -.34 | |
| 1.18 | -.90 | .70 | -.34 | .24 |
| 1.18 | -.98 | .70 | -.54 | .24 |
| 1.19 | -.98 | .78 | -.54 | .37 |
| 1.19 | -.99 | .78 | -.62 | .37 |
| 1.20 | -.99 | .82 | -.62 | .44 |
| 1.20 | -1.00 | .82 | -.66 | .44 |
| 1.20 | -1.00 | .83 | -.66 | .46 |
| 1.20 | -1.01 | .83 | -.68 | .46 |
| 1.20 | -1.01 | .84 | -.68 | .47 |
| 1.20 | -1.01 | .84 | -.68 | .47 |
| 1.20 | -1.01 | .84 | -.68 | .48 |
| 1.20 | -1.01 | .84 | -.69 | .48 |

Table 7.1

$\alpha$-effect (i.e., leftward effects with a factor of $\alpha$), which, in turn, leads to a cascading of effects which must then be modelled on a computer. A typical example of this is given in Table 7.1, where $\alpha$ = - 0.2 and $\beta$ = -.7. The rows show the successive activation values of each sequential element.

This is seen graphically in Figure 7.3. The first point to notice is that the effects of Perfect Grid have been built into the local structure of this network. The $\alpha$- and $\beta$-effects give rise to a pattern of alternating positive and negative numbers through local lateral inhibition of this sort, and equilibrium is quickly reached.

propagation of activation
alpha= -0.2   beta= -0.7
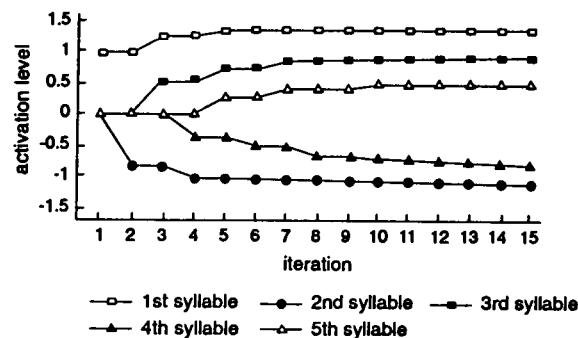


Figure 7.3: Evolution of a 5 unit system

Let us consider how Stress Clash Avoidance is also directly modelled by this system. Consider the result of placing an initial pattern of '1' unit of stress on both the first and second syllables of the word in Table 7.1 above, along with two possible settings for $\alpha$ and $\beta$: one where $\alpha$ = -0.2, $\beta$ = -0.7, and one where the settings are the opposit), i.e., where $\alpha$ = -0.7, $\beta$ = -0.2. The curve of the derived forms (i.e., the first and second derivatives rather than the absolute values) is what is of interest to us, and these are in Figure 7.4 and Figure 7.5.

As the final equilibrium figures show, setting one of $\alpha$ or $\beta$ significantly higher than the other (i.e., not making them equal) leads to a situation in which, despite the inherent activation of both, only one settles into a state with an activation level close to the inherent value of 1.00. However, in both cases, only one of the elements is a local maximum and is, hence, phonologically stressed.

## Indonesian

Let us now consider a recent analysis of the stress system of Indonesian offered by Cohn 1989. Cohn's analysis is placed within traditional generative terms – in particular, within the framework of lexical phonology.[7] In certain respects, her account could hardly be more at variance with the principles outlined at the beginning of this paper: the analysis relies heavily on rule ordering and on derivations in which material

first two syllables activated
alpha = -0.2   beta = -0.7
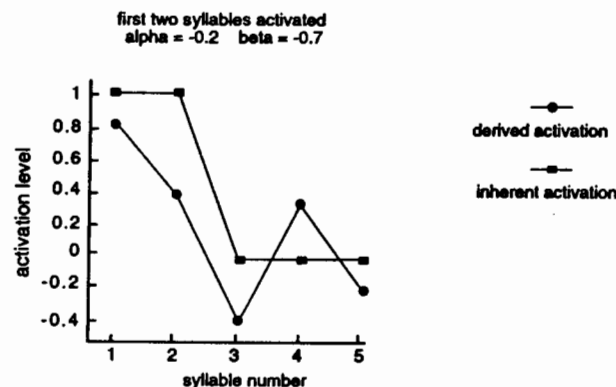
Figure 7.4: Beta-strong clash resolution

that is present at an earlier level of representation has an effect on the eventual surface form even though that material is deleted before it actually surfaces. Hers is an elegant analysis, using the resources of derivational lexical phonology in the most appropriate fashion.

Indonesian stress can be described in terms of a small number of simple principles; the facts are schematically illustrated in the bottom row of Table 7.2. Stress is applied to the penultimate syllable of a word as

first two syllables activated
alpha = -0.7   beta = -0.2
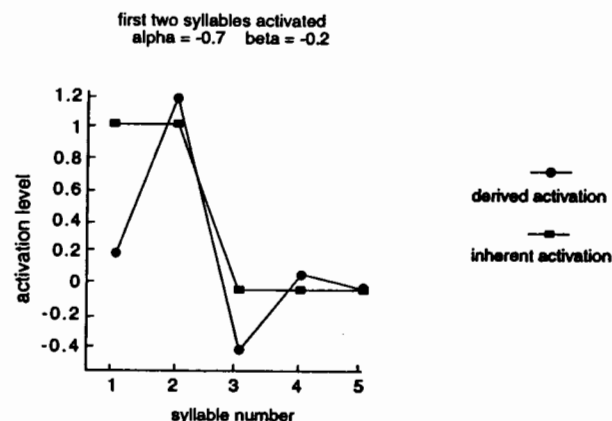
Figure 7.5: Alpha-strong clash resolution

Table 7.2: Noncyclic (monomorphemic) forms

| rule | σ σ σ | σ σ σ σ | σ σ σ σ σ | σ σ σ σ σ σ |
|---|---|---|---|---|
| 1 | ( ) | ( ) | ( ) | ( ) |
| 2 | • | • | • | • |
| 3 | stress clash | • | • | • |
| 4 | | | | • |
| | σ σ′ σ | σ′ σ σ′ σ | σ′ σ σ σ′ σ | σ′ σ σ′ σ σ′ σ |

well as to the first syllable. If these two are adjacent (i.e., if the word has three syllables), the first syllable fails to be stressed: stress clash in this case resolves to the right-hand (penultimate) element. In addition, if the word is long enough, alternate syllables to the left of the main stressed penultimate syllable are stressed, though if this should lead to a stress on the second syllable and, hence, a clash with the first syllable, this alternating stress is suppressed. The rightmost stressed syllable is, predictably, that which receives the highest degree of stress.

These facts can be implemented in metrical grid theory, as Cohn suggests, with the ordered rules in Example 7.2. Illustrative derivations are given in Table 7.2.

(2) Indonesian (Cohn's proposal)
(a) Final syllable is extrametrical
(b) End Rule: Final ("Penultimate Stress')
(c) End Rule: Initial (blocked if clash should ensue)
    'Initial Stress'
(d) Perfect Grid (Right to Left) (blocked if clash should ensue)

*Examples:*

| (A) bicára | 'speak' |
| (B) bìjaksána | 'wise' |
| (C) xàtulistíwa | 'equator' |
| (D) òtobìográfi | 'autobiography' |
| (E) àmerikànisási | 'Americanization' |

The stress system that we see in Indonesian is a clear example of the sort of system that should be modellable as well by the dynamic computational techniques discussed above. A model of the sort we have just considered, with $\alpha = -0.5$ and $\beta = 0.0$, provides precisely the right results–

Table 7.3: Monomorphemic forms

| number of syllables | stress pattern | values | | | | | |
|---|---|---|---|---|---|---|---|
| 3 | σ σ'σ | 0.20 | 1.0 | 0.0 | | | |
| 4 | σ'σ σ'σ | 0.95 | -0.5 | 1.0 | 0.0 | | |
| 5 | σ'σ σ σ'σ | 0.58 | 0.25 | -0.5 | 1.0 | 0.0 | |
| 6 | σ'σ σ'σ σ'σ | 0.76 | -0.13 | 0.25 | -0.5 | 1.0 | 0.0 |

stress clash avoidance in the correct direction and Perfect Grid effects (i.e., alternating stress leftward from the penultimate syllable) – if we place inherent stress (our K-function) on the first and penultimate syllables: 1.0 on the penult and 0.7 on the first syllable. Needless to say, no ordering is necessary or possible. The relevant numbers are given in Table 7.3.

An especially interesting aspect of Cohn's treatment of Indonesian involves what she argues is a cyclic application of several rules, applying first to a base word to produce a derived form and then once again to a larger form 'after' a suffix is added.

The facts, as Cohn describes them, are as given in Example 7.3 for words composed of a stem plus a suffix (i.e., the case of words analyzed with two cycles), and the forms with two suffixes (analyzed with three cycles) are given in Example 7.4. The interesting cases are those where the stress is assigned in a fashion different from that found with monomorphemic forms.

(3) Two cycle case
   (A) [[σ σ'] σ
   (B) [[σ σ σ'] σ]
   (C) [[σ' σ σ σ'] σ]
   (D) [[σ'σ σ σ σ'] σ]

(4) Three cycle case
   (A) [[[σ] σ'] σ]
   (B) [[[σ' σ] σ'] σ]
   (C) [[[σ σ' σ] σ'] σ]
   (D) [[ σ'σ σ' σ] σ'] σ]

A crucial case is given in Table 7.4, the case where, as Cohn shows, a monomorphemic six syllable word has a different stress pattern from a six syllable word that is composed of a five syllable base plus a suffix

Table 7.4

| | σ σ σ σ σ σ | | | | | |
|---|---|---|---|---|---|---|
| 1st cycle | σ σ σ σ σ | | | | | |
| 1 | | | | | () | |
| 2 | | | | • | | |
| 3 | | • | | | | |
| 4 | does not apply (clash avoidance) | | | | | |
| 2nd cycle | • σ | σ • σ | σ | σ | σ | |
| 1 | | | | | () | |
| 2 | | | | | • | |
| 3 | | • | | | | |
| 4 | does not apply (clash avoidance) | | | | | |
| output of 2nd cycle | • σ | σ | σ • σ | • σ | σ | |
| stress clash reduction | • σ | σ | σ • σ | σ | σ | |
| output | σ' σ | σ | σ | σ' | σ | |

added only after the base has been processed as an independent word. The derivation for the monomorphemic, noncyclic form was given above in Table 7.2; her cyclic derivational account is sketched in Table 7.4.

Cohn suggests that the missing stress on the third syllable of the bimorphemic word in Table 7.4 is due to the presence of a stress on the fourth syllable (which is the penult of the inner cycle). That 4th syllable stress is lost, however, on the second cycle, when the 5th syllable receives a stress (it now being the penultimate syllable in the word), and the 4th syllable loses its stress due to the effects of an additional stress-deleting rule that applies when stress clash arises.

Our present model derives the correct result with a good deal less machinery than Cohn's and with no intermediate hidden representations. The values generated are given in Figure 7.6a, and are, as we see, accurate predictions. These results are derived by interpreting cyclicity
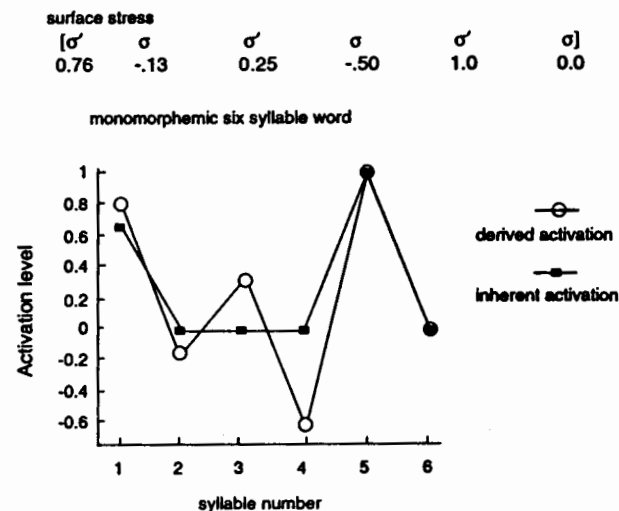
surface stress

| [σ′ | σ | σ′ | σ | σ′ | σ] |
|---|---|---|---|---|---|
| 0.76 | -.13 | 0.25 | -.50 | 1.0 | 0.0 |

monomorphemic six syllable word



Figure 7.6a: Six syllable word

not as a derivational notion but, rather, as a statement about phonological structure.[8] Thus in a six syllable word of the sort in Figure 7.6b, the fourth syllable is the penult of the inner word (and thus receives a positional activation of 1.0), while the fifth syllable is also the penultimate syllable – of the outer word; it too receives positional activation of 1.0. Quite generally, to say that a structure is cyclic is to say that it has nested phonological word structure (i.e., structure of the form

$$[w_2 \ [w_1 \ xx \ ]_w \ yy \ ]_{w_2}).$$

Some words quite transparently have internal word structure, such as the word *Indianaism*, for example, which plainly contains the word *Indiana*, or the compound *driftwood*, containing a sequence — *ft* — which would not be possible as a word-internal coda. Not all morphologically derived words are of this phonological form; *Buddhism*, for example, is derived from *Buddha + ism*, but undergoes effects occasioned by the lack of any internal word structure. In short, phonological structure and morphological structure are different; and those robust effects traditionally ascribed to cyclicity are due to nested phonological word structure.[9]

Hence if a language assigns stress to the penultimate syllable of a word, and a nested phonological structure is found, then both the 4th

surface stress

| [[σ′ | σ | σ′ | σ | σ′] | σ] |
|---|---|---|---|---|---|
| 0.64 | 0.13 | -0.25 | -.50 | 1.0 | 0.0 |

two 'cycles': bimorphemic, six syllables
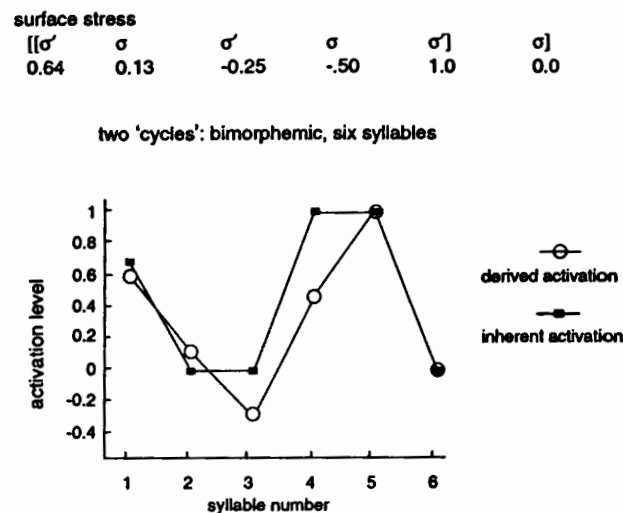


Figure 7.6b: Five syllable word plus suffix

and the 5th syllables will receive inherent activation in their capacities as the penult of the internal and the external phonological word, respectively.

As we see in Figure 7.6b, as well, the activation assigned to the 4th syllable has an effect without leading to that syllable being stressed on the surface. At the same time, this result is achieved without hidden representations; it is, rather, achieved by means of a crucial character of the model – the presence of significant subthreshold difference. As we can see, the 4th syllable's activation value is strikingly different in Figure 7.6a and b; this difference is the sum total of the effects on that syllable, and this difference, in both cases, has an effect on the lack of stress on the syllable that precedes it. On the other hand, as we have seen, there are no hidden representations; the forces at work affect each other simultaneously and seek a stable resolution of their requirements.

We present in Table 7.5 and Table 7.6 the relevant calculations of all the forms.

## Syllabification

The local dynamic computational models of phonological systems which are being explored in this paper were originally motivated by the study of syllabification systems.[10] In this section I will only sketch this

| number of syllables | stress pattern | values | | | | | |
|---|---|---|---|---|---|---|---|
| 3 | σ σ' σ | 0.50 | 1.0 | 0.0 | | | |
| 4 | σ σ σ' σ | 0.45 | 0.5 | 1.0 | 0.0 | | |
| 5 | σ' σ σ σ' σ | 0.83 | -0.25 | 0.5 | 1.0 | 0.0 | |
| 6 | σ' σ σ σ σ' σ | 0.64 | 0.13 | -0.25 | 0.5 | 1.0 | 0.0 |

Table 7.5: Two cycle forms

| number of syllables | stress pattern | values | | | | | |
|---|---|---|---|---|---|---|---|
| 3 | σ σ' σ | 0.50 | 1.0 | 0.0 | | | |
| 4 | σ' σ σ' σ | 0.75 | 0.5 | 1.0 | 0.0 | | |
| 5 | σ σ' σ σ' σ | 0.33 | 0.75 | 0.5 | 1.0 | 0.0 | |
| 6 | σ' σ σ' σ σ' σ | 0.69 | -0.38 | 0.75 | 0.5 | 1.0 | 0.0 |

Table 7.6: Three cycle forms

issue in very broad strokes and will leave a detailed discussion for another place.[11]

We hypothesize that the characteristics that we have established for stress systems (i.e., for our interpretation of metrical grids) hold equally of the skeletal tier, and t' at the envelope – the ups and downs – of activation of the skeletal positions is interpreted linguistically as syllable structure, in precisely the same way that the ups and downs of the grid positions are interpreted (in more and less complex ways) as stress and foot structuring.

We drew a distinction above regarding inherent activation and derived activation that remains quite useful for us. When we focus on syllabification and the skeletal tier, we are soon led to the conclusion that the *inherent* activation of a segment is its (inherent) sonority, while the derived activation is a contextually determined function of its inherent sonority.

Why should this be? The answer is not hard to see. Sonority is, fundamentally, the propensity that a segment has to be the nucleus of a syllable. The most sonorous segment, *a*, has no choice; it must be the nucleus of its syllable. The least sonorous elements, the voiceless stops,

have the least chance to be located in the nucleus of their respective syllables. Segments in between vary with respect to whether they will be nuclear, and the ways in which they vary involve both language-particular determinants (*l* may be syllabic in English but not in Spanish) and contextual determinants (*l* is not syllabic before a stressed syllable in the same word).

Thus we may consider the possibility that the determination of syllabification involves the same kind of contextual calculations involving inherent sonority and relative position that we considered in the preceding work. Elements with an activation above a certain threshold (call it N) will in effect play the role of the nucleus of their syllable; those below a certain threshold (call it O) are onset elements; and those with an activation level between O and N are coda elements.

```
        ---> increasing derived activation
-------------|--------------------|-------------------
  onset   O         coda    N            nucleus
```
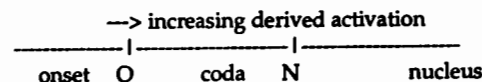
The models of lateral inhibition we have considered so far have the natural property that, in the absence of any inherent activation, they create up and down waves that change direction with each unit. In the simplest case, as we have seen, this create a situation in which the derived activations are alternating between positive and negative numbers. If we consider the trivial case where the two thresholds are both zero (O=N=0.0), then this statement amounts to the natural observation that if one could speak a spoken language without using any segments at all it would consist of sequences of onset-nucleus ( ... ONONONON ... ): that is, the rhythmicity of syllabification follows as much from the network organization of the phonological system as it does from the choice of the segments themselves.

## The Broader Picture

There is another motivation for the work that has been reported in this paper that goes beyond interest in connectionist-type modelling of phonological processes. In several recent papers (Goldsmith 1989, 1990), I have argued for a conception of phonological theory that is neither static nor derivational. Work to date on phonological theory has largely assumed – implicitly – that, much along the lines of M. Jourdan's tutor's approach, any theory that was not static in design was ipso facto derivational. The approach that I have been developing – which I call 'harmonic phonology' – posits three phonological levels (M-level, W-level, and P-level) and also posits dynamic processes on each level. Thus each

level is not static; it does not consist of a single representation. However, the structural modifications that occur on each level are not just part of the wide range of effects possible within the confines of a production system (i.e., traditional generative rules); all changes serve to increase the well-formedness of a structure in a fashion that is constant across the language.

However, it is no simple task to elaborate a theory of phonological representation *cum* theory of dynamic simplification from scratch. The present research is offered as one case study – one example – of this sort. The construction of accent patterns and of syllabification is now widely regarded, correctly, as a significant portion of the phonology of any given spoken language, and the present systems are offered as an example of how a dynamic, but nonderivational, phonology may be considered as a live, interesting, and explanatory alternative to the generative conception.

## Notes

1   I am grateful for very helpful discussions with Tom Bever and most especially with Gary Larson, who has made several suggestions that have substantively improved this paper; I am also grateful to members of the audience at the presentation of some of this material at the University of Rochester; Michael Tanenhaus made some suggestions that have been incorporated here. In earlier stages of this work, I also appreciated helpful comments by David Corina, Jeff Elman, Mary Hare, George Lakoff, and David Perlmutter, and, especially, Caroline Wiltshire. This paper was written in December, 1989, and revised in May, 1991. This material is based in part upon work supported by the National Science Foundation under Grant No. BNS 9000678.

2   I also presume a familiarity with both the style and content of phonological research.

3   For a detailed description of the metrical grid, the reader may consult Goldsmith 1990, Chapter 4.

4   Or perhaps a mora; see Goldsmith 1990 for discussion.

5   A brief mathematical excursus may be of interest to some readers. If we consider the effect of the network as a mathematical operator applying to the vector which represents the state of the network at any given moment $t$, then that operator $M$ is built simply out of an $n$ by $n$ matrix, where $n$ is the number of units. We define $M$ as being zero everywhere except on the supradiagonal, the diagonal above the major diagonal, where it is $\alpha$ (i.e., $x_{i,j+1} = \alpha$), and the subdiagonal, where it is $\beta$ (i.e., $x_{i,j-1} = \beta$). If we call the initial state of the system the vector $v$, then after $k$ iterations, the system is in a state defined by $v + M^k(v)$, where $M^k$ is the $k$th power of $M$.

6   See Goldsmith 1990, Chapters 3 and 4, and references there.

7   See Kiparsky 1982, and also Goldsmith 1990, Chapter 5.

8   This point is discussed in greater detail in Goldsmith 1990 and in print.

9   That phonological word structure can be nested (i.e., recursive) is no more surprising than that syntactic structure can and, in a sense, must be: we find full finite (tensed) clauses within other finite clauses, quite obviously, and hardly give the matter a moment's thought. On the other hand, just as a word can be combined with another morpheme and not retain its character as a phonological word, so too can a sentence be combined as part of a larger sentence and not maintain its independent syntactic status; in the literature, this is known as clause union.

10   I have gained much from conversations with Gary Larson, of the University of Chicago, on this topic; Larson is also developing some approaches of his own to local modelling in phonology. My thinking has also been influenced here by recent unpublished work by G.N. Clements on sonority slopes and their relation to well-formed syllabification.

11   Larson and I have several papers in progress on this point. Two early discussions have appeared: Goldsmith and Larson 1990 and Larson 1990.

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