Universal Phonology
A SGER Proposal

Alan Prince (PI)
Brandeis University
Linguistics and Cognitive Science Program

Paul Smolensky (Consultant)
Dept. of Computer Science
University of Colorado at Boulder

INTRODUCTION

What. We propose to work out a new approach to phonology, developing a theory that we can now sketch both in broad outline and in several particular problem areas. The goal of this theory, simply put, is to build the phonologies of particular languages directly from the principles of universal phonology. Within standard views of phonology, such a project is simply not feasible, as Halle & Bromberger (1989) have shown. Although phonologists currently have a good sense of what many of the universal principles and tendencies are, the actual apparatus of description pretty much leads its own formal life separate from these guiding intuitions. Analyses which accord with the universal principles are regarded favorably in the community of researchers, but the principles themselves typically do little if any formal work -- this is done by procedural rules and ordering statements that could just as well violate as agree with the informally-acknowledged principles. If Halle & Bromberger are right, phonology can do no better and must remain quite unprincipled, in sharp contrast to syntax, and in conflict with the fundamental aims of generative grammar.

We do not accept this pessimistic conclusion. Our diagnosis is that the flaw in the standard theory lies in the specific notion of procedural computation that it espoused nearly four decades ago, long before the representational discoveries of the recent era, which have given rise to metrical and autosegmental phonology, and long before the development of sophisticated parallel algorithms. We propose to radically revise the notion of formal computation in linguistic theory, introducing an entirely new formalism for managing the interaction of principles of well-formedness, based on fundamental results in higher-level analysis of the dynamics of connectionist networks. Our general theoretical goal is to show how this new method of regulating systems of principles provides for a deep and constrained characterization of natural language phonology. Our specific target is a research monograph to be submitted for publication about a year from now, which we outline below. We believe this monograph would be likely to have a major impact on the course of phonological theory, with implications extending more generally throughout formal linguistics and into the cognitive science of language.

Why us. The new theory uses general computational principles from the connectionist approach called Harmony Theory. For this research, the collaboration of Prince and Smolensky is essential. Prince is not only a contributor to modern phonological theory, he is virtually unique among linguists in having developed a technical understanding of connectionism and a belief that,

The distinction between PI and Consultant was an artifact of NSF technicalities of the era.

-AP, PS.
properly used, connectionist techniques could lead to major advances within formal linguistics. Smolensky, who developed Harmony Theory, is unique among connectionists in his commitment to developing higher-level connectionist formalisms that can integrate with and enrich symbolic theory. For the past several years his work has been moving towards applications in linguistics. Our collaboration has been in formation since May 1988.

Why now. Connectionism is just beginning to make its presence felt in theoretical linguistics. Other investigators are attempting to use connectionism to move phonological theory away from symbolic analysis, seeking either to abandon higher level constructs in favor of what amounts to statistical data analysis, or to find relatively straightforward correlates in connectionist hardware for established symbolic notions. One could portray this as trying either to move phonology downwards in level of abstraction (towards data analysis), or to move it sideways, replacing theoretical constructs by near-equivalents. By contrast, we see the big payoff as lying in the use of connectionism to move phonological theory upwards from the procedurally-encoded, highly stipulative language-particular rule systems to a base of declarative, universal principles, modulated by language-particular parameters. We believe that connectionist computational ideas, played out over the structural discoveries of the last 15 years of linguistic theory (metrical and autosegmental representations in particular), can give rise to a far deeper, more principled theory than is currently deemed possible with standard approaches.

After meeting twice a year for a few days for almost two years now, our long-distance collaboration has finally gelled to the point that rapid progress could be made if we are able to meet on a more extended basis. Prince will be on sabbatical leave next year, and the sabbatical salary funds and travel support requested in this proposal would enable him to spend considerable time in Boulder. Thus the modest funds of a SGER grant are both necessary and sufficient for the proposed research to be pursued in earnest.

Why SGER. The proposed research is certainly high risk. It employs a completely new approach that would be impossible to substantiate to the high degree necessary to win normal NSF funding. Furthermore, by the very nature of the approach, it is unlikely to receive even-handed review at this point. Linguists are likely to view the proposed mode of computation with reflexive disdain, and connectionists are likely to be unreceptive to the linguistic goals of the project.

However, if we can successfully fill out the research sketched below, there is little doubt that the result could be a turning point for phonological theory. For the first time, universal principles will constitute the formal theory itself, not the informal motivation for the theory. Further, the computational framework will integrate connectionist with symbolic principles, opening formal phonology to intimate interaction with connectionist cognitive modeling in such areas as language acquisition, real-time processing, and neurolinguistics.

The work. In the remainder of this proposal, we briefly outline the monograph that forms our specific target product; then we conclude with discussion of two examples illustrating our method of attack on specific problems.

The monograph. We will present a new formalism for linguistic theory based on the notion of numerical optimization. Universal grammar specifies a function $H$ - the Harmony Function - which
numerically measures the well-formedness of linguistic structures. This function depends on language-particular parameters, which determine the relative priorities of the universal well-formedness constraints embodied in H. The structure the grammar assigns is that which maximizes or optimizes H.

The monograph will be structured as follows. To lay the groundwork, in the first chapter we discuss the role that optimization has previously played in linguistics; our goal of using optimization to replace rules by universal principles; the connectionist foundation of our use of optimization; the relation of our theory to other connectionist approaches to phonology; and give an outline of the theory. In the second and third chapters, we apply this theory in considerable detail to syllable structure and to stress theory, two central areas of current linguistic research that boast an impressive body of findings as well as a large, complex empirical base. In the fourth chapter, we survey other areas of phonology in less depth, indicating how the theory applies there. We conclude with a discussion of the relation between the descriptive theory, computational algorithms, other aspects of linguistic theory such as syntax, and cognitive modeling.

Syllabification. Dell & El-Medlaoui (198*) have discovered that in Berber any segment at all can serve as the nucleus of a syllable -- not just vowels. This results in tremendous potential structural ambiguity for a string of segments; but they find that in most cases the syllabification is unique, the chief factor being intrinsic sonority. Their basic algorithm for imposing syllable structure can be summarized like this:

Operation: In a sequence of segments XY, make X into the onset, Y into the nucleus of a syllable.

Procedure: Given a string S, apply the operation to pairs of segments AB in S, where B is the most sonorous segment remaining unsyllabified in the string. Repeat the operation, descending the scale of sonority, until the operation can no longer be applied.

The procedure is set up to guarantee that the intrinsically more sonorous segments in the string will end up as syllabic nuclei. From the point of view of phonological understanding of the syllable, this is entirely desirable -- vowels and the segments most like vowels should be syllable peaks. Yet this is formally arbitrary in the actual algorithm: from the formal point of view, one could have just as easily said: apply the operation to AB, where B is the LEAST sonorous segment in the string, working up the sonority scale from the bottom instead of down the scale from the top. Thus, the Dell-El Medlaoui algorithm provides a perfect example of the disjunction between formal analysis and the real guiding principles.

The way to resolve the formal conundrum is to recognize explicitly what is merely implicit in the given algorithm -- that highly sonorous segments are universally preferred as syllable nuclei. Suppose we set up a sonority ranking, ranging from 1 (least sonorous) to some positive integer k for most sonorous. We can employ this in a Harmony Function as follows: we reward each syllable with the rank of its nucleus, and sum the rewards over the domain of syllabification. The actual syllabification of the string will be the most harmonious of the possible syllabifications: from the form of the Harmony Function, it follows that the most sonorous segments will be taken as nuclei. No special syllable-building algorithm, with formally arbitrary properties, appears in this account: everything follows from the substantive principle that nuclei are sonorous, coupled to the formal principle that the harmony of strings of units is the sum of the harmony of the units.

The story becomes more interesting when further dimensions of syllable well-formedness are taken into account. We will show
that structural harmony (open syllables preferred to closed) interacts nonlinearly with nuclear harmony to predict a variety of cases where the full Dell-El Medlaoui algorithm is unsatisfactory or arbitrary.

Stress. The factors that influence stress patterns include, in addition to the rhythmic constraints determining the preferred form of stress—feet, a set of independent constraints relating to syllable quantity and word-position (cf. e.g. Prince 1983, 1985, 1990; Hayes 1985, 1986). In terms of Harmony Theory, favored configurations earn a reward $R$, disfavored configurations impose a penalty $P$.

Some universal stress principles:

- a. Heavy syllables should be stressed. ($R_{heavy}$)
- b. Do not stress last syllable. ($P_{last}$)
- c. Place stress near the edge of the word. ($R_{edge(k)}$)
- d. Rule of combination as above: addition.

What this means is that in a structure where the last syllable is stressed, we add the negative quantity or penalty $P_{last}$ to its $H$ value; similarly, if a stress falls $k$ segments from the edge of a word, we add the non-negative quantity or reward $R_{edge(k)}$ to $H$, where the reward lessens as we go in from the edge. The parameters $R_{heavy}$, $P_{last}$, and $R_{edge(k)}$ govern the relative priority of these principles, and are to some degree language dependent. By varying such parameters, we explain the typology of quantity and edge effects in the stress systems observed in the world’s languages.

Consider first the simple edge effects. If $k$ in $R_{edge(k)}$ counts from the beginning of the word, we expect initial stress. But if it counts from the end, then interaction with $P_{last}$ will drive stress to the penult. Initial and penult stress, either as secondary or main, are undoubtedly the most common observed patterns.

If we bring in quantity, further interactions perturb the pattern. A typical example, given by the Indian language Maithili, is:

- a. Stress is by default penultimate.
- b. If the final syllable is heavy (that is, contains long vowel) and the penult light, the final is stressed.
- c. And if both final and penult are light, while ANTEpenult is heavy, the antepenult gets the stress.

This pattern arises from (e.g.) the following choice of parameters:

- a. $R_{heavy} = 1$
- b. $R_{edge(1)} = 1$; $R_{edge(2)} = 1/2$; and $R_{edge(k)} = 0$ if $k > 2$.
- c. $P_{last} = -3/4$

The cases fall out like this:

- a. All light syllables in word -- Penult wins.  
  Penult beats Final: $R_{edge(2)} > R_{edge(1)} + P_{last}$:  
  $1/2 > 1 - 3/4 = 1/4$
  Penult beats Antepenult: $R_{edge(2)} > R_{edge(3)}$:  
  $1/2 > 0$

- b. Heavy final syllable, light penult -- Final wins.  
  Final beats Penult: $R_{edge(1)} + P_{last} + R_{heavy} > R_{edge(2)}$  
  $1 - 3/4 + 1 > 1/2$
  Final beats Antepenult, even if AP heavy:  
  $R_{edge(1)} + P_{last} + R_{heavy} > R_{edge(3)} + R_{heavy}$  
  $1 - 3/4 + 1 > 0 + 1$

- c. Heavy antepenult; penult and final light -- Antepenult wins.  
  Antepenult beats Penult: $R_{heavy} + R_{edge(3)} > R_{edge(2)}$  
  $1 + 0 > 1/2$
Antepenult beats final: Rheavy + Redge(3) > Redge(1) + Plast 
\[ 1 + 0 > 1 - 3/4 = 1/4 \]

The role of the penalty for final stress is clearly revealed when we orient the edge evaluation to the beginning of the word. In this case, using exactly the same values as above, stress will fall by default onto the initial syllable; but just in the case where the second syllable is heavy and the first is light will stress appear on the second syllable. (The Dravidian language Malayalam shows exactly this pattern.)

\[ \text{Rheavy} + \text{Redge}(2) > \text{Redge}(1) \]
\[ 1 + 1/2 > 1 \]

The significance of these results is underlined by the fact that such patterns have been resistant to elegant formulation in foot-theoretic terms. We assert that this is because the determinant of these patterns is the relation between quantity, edges, and prominence; and it is only in a theory like the one being contemplated here that the relevant comparisons can be made between these different dimensions of well-formedness.

References.
Dell, F. and El-Medlaoui
Halle, M. and S. Bromberger
Hayes
Prince
Maithili - Malayalam
Smolensky, Harmony Theory 8 OBS?