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A connectionist model of poetic meter

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Traditional analyses have not explored fully the interaction of various elements which affect stress patterns of a line of poetry in performance. A connectionist model of James McClelland and David Rumelhart in *Explorations in Parallel Distributed Processing* (1988) is applied to the analysis of English poetic meter. The model graphically illustrates the dynamics of a reading of a poetic line and incorporates a number of features associated with the performance of a poetic text, while providing a notational system that allows mathematical analyses of poetic meter as it is realized in performance.

1. Introduction

One of the salient features of poetry is its metrical structure. Poetry in English often uses regular patterns of stress to achieve specific aesthetic effects; readers expect such patterns and foreground them in their oral interpretations of the poems, whether they be read aloud or subvocally. Consider the opening line to Wordsworth's *Tintern Abbey*: 'Five years have past; five summers, with the length ...'. According to traditional rules of scansion, this iambic pentameter line would receive a heightened stress on the alternate even numbered syllables *year*s, *past*, *sum-*, *with*, and *length*. Yet the repetition of the adjective *five* calls for some degree of emphasis upon each occurrence of the word, even though it is found in an unstressed position. But how much emphasis? More than the 'stressed' *with*? More than *years*? Is the stress equal in both uses of *five*? And from where does stress or emphasis come – from an act of interpretation, or from an intonation pattern generated by the syntax? From lexical accent (as in *sum*mers) or from an attempt to emphasize a key element in the prosody of the poem?

Such questions are legitimate, for poetry is a highly rehearsed speech act; the speaker has made interpretive decisions concerning the role of each word

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in its context, although the speaker may or may not embody all those decisions directly in a performance of the poem. Likewise, the poet has made decisions concerning the relative impact of each word on the total rhythm of the line and has structured the poem in accordance with intended and sometimes fortuitous effects. This single line indicates the problems facing an analysis of poetic meter. A full understanding of metrical rhythm in performance of a line of poetry – what Jakobson (1960) terms a 'delivery instance' in distinction from a 'verse instance' or underlying metrical structure of a line – requires us to consider a linguistic analysis of the line, the interpretations a reader might make of the line's meaning, the force of individual words within the line, and the effect of the various prosodic devices a poet uses.

The traditional or classical approach to metrical analysis has been by way of a notational system and a terminology borrowed from Latin quantitative verse. The system has been surprisingly resilient, primarily because of its simplicity and flexibility; traditional metrics is still widely taught in poetry classes. Dividing a line into units (feet) has allowed the creation of a vocabulary to describe some of the perceived effects of poetry. That poets themselves were aware of this system and consciously experimented with meter in its terms has helped justify it and has masked its shortcomings.

Chief among these shortcomings has been traditional metrics' inability to account for the interaction between all units in the line: to consider the line, that is, as a whole. Similarly, traditional metrics has no way to distinguish degrees of metricality or to decide if a line is metrical or not. Halle and Keyser (1971) provided an alternative mapping of poetic meter, with a series of generative rules making use of syntactic boundaries to provide a measure of complexity and, ultimately, of metricality. Kiparsky (1975, 1977) incorporated the deep structure of words and phrases to account for certain ambiguities in Halle and Keyser's work. Among the more important innovations of Kiparsky's analysis was the distinction between metrical and prosodic rules; metrical rules generate, from a set of basic patterns, the abstract metrical patterns underlying the verse, while prosodic rules show how the metrical patterns may be linked to linguistic representations (Harvey 1980). The ways these rules are phrased and the circumstances under which they are violated can be particularized to individual poets.

Since Kiparsky's articles, the most interesting work has been in grid-based theories (Hayes 1983, 1984, 1989), in Attridge's (1982, 1987, 1989) system of base rules and deviation rules, and in statistical analyses (Youmans 1986, 1989a,b; Gasparov 1987). These systems of analysis are strongest in their ability to describe both what is permissible in particular linguistic settings and ways in which individual poets have defined which rules must be adhered to and which may be violated in systematic ways.

There are, however, two areas which may have significance for an understanding of poetic meter which are not dealt with strongly by systems of

generative metrics. First, as suggested above, a reader's interpretation of a poem will affect the production of a metrical pattern for a particular line. In the line from Wordsworth cited above, one reader might choose to emphasize the exact number of years, '*five* years' and '*five* summers'. Another might focus on the time periods, 'five *years*' and 'five *summers*'. In systems of generative metrics, and traditional metrics as well, both readings are allowed, though the first involves several permissible rule violations, creating a degree of complexity or tension in the line. Similarly, the repetition of sounds in a line of poetry, whether through assonance, alliteration, rhyme, or the repetition of an entire word, such as 'five', might well be emphasized by a reader, again affecting the actual stress pattern which emerges in a performance. Which reading is chosen, and hence which rhythmical pattern appears in a performance, will depend not only upon the outcome of linguistic rules, but also upon the interaction of these rules with interpretive decisions made by the reader.

Another area of difficulty in both traditional and generative systems of metrical analysis is notation. Stress is most often listed as a binary value (strong or weak), a trinary value (as in grid-based systems), or a quadrinary value (Harvey 1980). Even when such values are understood as relational rather than as absolute values, there may be difficulties in quantifying such values. Attridge (1982) argues that 'An underlying rhythm manifested in a metrical pattern exerts a simplifying pressure on the complex stress contour of the language, so that the reader of regular verse perceives not a multiply-gradated hierarchy of stresses, but a pattern made up only of two kinds of syllable, relatively strong and relatively weak, or stressed and unstressed' (p. 160). Yet an analysis in those terms misses, I believe, some of the richness of stress functions within these multiple gradations of stress which contribute to the performance of poetry. Indeed, some systems of analysis are made even more difficult to quantify by the use of symbols, such as w S, +s −s, o B, ´ `, underlining, and, in grid theories, one or more x's above a word. Some mathematical systems of analysis, such as Blain's (1987) model of alliteration, require a notational system that can be used computationally. This is not to say, however, that computational methods cannot be used with binary systems. Such features as stress and word onset have been, for example, the basis of frequency and distribution analyses to distinguish literary style (Greenblatt 1973, Chisholm 1981).

2. Connectionist models

The connectionist model provides a system of metrical analysis that, first, will account for the contributions both of linguistic elements (as in systems of generative metrics) and of a reader's interpretations to the rhythm of the

poetic line; second, will describe features in possible performances of the verse; and third, will provide a notational system useful for mathematical analysis. This model represents a way of looking at meter which complements that of generative metrics in that it considers the role of underlying lexical and syntactic structures in creating stress patterns. Yet it focusses on building a model of performance which will be useful in understanding both the ways by which readers might arrive at the rendering of a line of poetry and the differences readers perceive between metrical regularity and metrical complexity. I will suggest as well that the model might be useful for quantifying distinctions between the works of individual poets.

The use of connectionist frameworks to model psychological processes has been detailed by McClelland (1988). Briefly, connectionist or parallel distributed processing models view cognitive processing not as a strictly linear operation or sequential series of operations but as an active and simultaneous interplay between a number of individual but interconnected units. As Rumelhart and McClelland (1986) say, 'These models assume that information processing takes place through the interactions of a large number of simple processing elements called units, each sending excitory and inhibitory signals to other units. In some cases, the units stand for possible hypotheses about such things as the letters in a particular display or the syntactic roles of the words in a particular sentence. In these cases, the activations stand roughly for the strengths associated with the different possible hypotheses, and the interconnections among the units stand for the constraints the system knows to exist between the hypotheses' (p. 10). The activation of units spreads from one to the next, the amount of activation dependent on the strength or weight of the connection between the units, the initial input to the system, and the bias of the unit, or its inherent tendency towards activation. Because the units are interconnected, the activation of any one unit tends to affect the system as a whole, though as not all units are directly connected to one another or connected in the same ways, the system is neither simple nor linear. Measuring the activation of a particular unit takes place repeatedly – an updating – as the unit continues to be affected by, and to affect, changes in the activations of surrounding units. Activation of the unit is measured on a scale of 0 to 1, 1 representing total activation. The system is not strictly linear, for the updatings may occur randomly; any two runs of the system will thus have different configurations, though they eventually tend toward similar patterns. This suggests a basic difference between a connectionist model and generative metrics, in that while generative metrics delivers a structural description of the line, the connectionist model is processional, generating over time a pattern derived from repeated interactions of units. Connectionist models have been used to examine a number of situations involving learning, language processing, perception, decision making, and other cognitive functions (see, for example, Rumelhart

and McClelland 1986, Dell 1989, Elman 1989, Kintsch 1988, 1990. For a critique of connectionist models see Fodor and Pylyshyn 1988.)

3. The constraint satisfaction model

The particular connectionist model I have chosen to apply to an analysis of poetic meter is a constraint satisfaction model. The model is useful for analyzing cases in which there are competing constraints or possible solutions to a problem which need to be reconciled or satisfied. McClelland and Rumelhart (1988) describe the constraint satisfaction model as a system wherein each individual unit may be thought of as a hypothesis, while the connections between units are seen as constraints among hypotheses. The connections between units may be positive or negative, indicating that the activation of one unit may support or disconfirm the hypothesis of the unit to which it is connected. Some of the constraints may be seen as more important than others, reflected by a larger weight in the connection strength of that constraint. There is also the possibility of a unit receiving external evidence, which McClelland and Rumelhart (1988) construe as 'direct evidence for certain hypotheses' (p. 50); this is represented as an input to the system through the individual unit. Finally, there is the possibility for an a priori probability for a particular hypothesis, represented as a bias which operates without additional evidence. In this model the system attempts to satisfy as many constraints as possible, balancing the number and strengths of the connections between the units, the initial inputs, and the initial bias. The model has been fruitful in analyzing events as simple as the perception of a Necker Cube and as complex as the choice of scientific theories or juried legal decisions (Thagard 1989). A computer model is provided by McClelland and Rumelhart (1988).

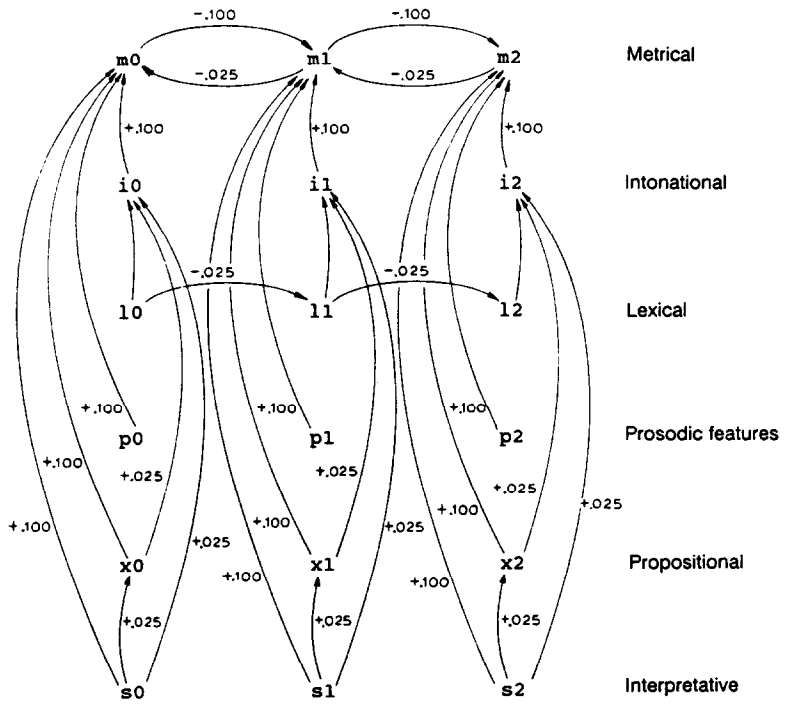
In the case of poetry based upon an accentual-syllabic metrical system, such as English iambic pentameter verse, we might say that for each syllable in a line of poetry there is a unit representing a hypothetical amount of emphasis or stress for that syllable. The line – which I have termed the 'metrical line', for it is here that the meter is finally realized – then consists of ten sequential units representing positions to be filled by syllables which will take on the amount of stress activated in those units. In iambic poetry, the underlying pattern is of alternating weak and strong stresses; the model reflects this with a bias or a priori probability built in to the system that alternate units beginning with the second will be stressed. Each unit in this metrical line is connected to other units in the system, which act as constraints on the amount of stress that each metrical line unit achieves. Into these other units inputs representing evidence favoring the possibility of stress may be placed. The probability that a particular syllable or unit in the

metrical line will receive stress will be the result of all the constraints that act upon that unit which serve to encourage or suppress that probability. In this particular model, units in the metrical line are connected to five other types of units, representing intonation, lexical stress, prosodic features, propositional features, and interpretive decisions.

The first constraint to be considered is intonation. There is a positively weighted connection between the pitch of a syllable achieved by virtue of its intonation and the amount of stress the syllable receives when spoken. This is rendered as an input to each intonational unit reflecting the intonation of each particular syllable in the line. The lexical features of individual words making up the line are the second constraint; each unit in the metrical line is connected to a unit representing lexical stress. The stress features of polysyllables are marked as inputs to the system. In addition, as these lexical features are related to intonation, there is a connection between lexical and intonational units as well. The prosodic features of the line (rhyme, assonance, alliteration, and so on), represent another set of possible constraints on the stress a syllable might achieve; a reader might accentuate alliteration through stress, for example. Thus each unit on the metrical line is connected to a unit representing a prosodic constraint, allowing a third set of inputs to the system. Stress might also be related to the significance of a word within the text base of the line. The main propositions within this text base receive an input, determined by a linguistic analysis of the grammatical base structure of the line. These units are also connected to those representing intonation and to those representing the fifth and last constraint, the reader's interpretation. Finally, words a reader deems important to the poem's interpretation may have an increased probability of being stressed and are given an input. The relative importance of each of these five constraints can be (and is) varied by the reader. Is alliteration emphasized? Should a play on words be foregrounded? Since intonation is affected by meaning and each reader makes interpretative decisions about meaning, various renditions of the line are likely. However, within the range of possibilities, certain patterns emerge, as will be seen. The particular manner in which the stress is manifested, however, may vary from reader to reader and from performance to performance.

In short, in this constraint satisfaction model of iambic pentameter verse, each unit in the metrical line, representing the potential for being stressed, is connected to five other units representing intonation, lexical stress, prosodic features, propositional features, and interpretative decisions. I have built into the system a bias towards stress in alternate, even-numbered positions. I have also built in negatively weighted connections between adjacent positions in the metrical line, with a greater negative weight to the following position, and a smaller negative weight to the preceding position. This bias and the negatively weighting of adjacent positions tend to force the line towards an

Table 1
The connection strengths between units representing syllable positions (first three syllables only).



iambic pattern, although not so strongly as to overcome high initial inputs in normally weak positions. In addition, some of the units are connected not only to units in the metrical line, but to each other as well. I have posited weak, positive connections between intonation and the lexical, propositional, and interpretative lines, and a weak positive connection between proposition and interpretation. The relationships between the positions are depicted in table 1.

The likelihood of a syllable being stressed – or the strength of activation associated with a particular syllable – will be the result of measurements of activation computed through a series of updatings. The measurement of a unit's activation is on a 0 to 1 scale; on this scale, 1 represents the complete activation of the unit. An updating of a unit's activation consists of calculating the activation of one individual unit based on measurements of its initial activation, input, and bias, and the activations and connection strengths of other units to which it is attached. A cycle represents the updating of all units in the system (here there are 60 units). In this model, 30 cycles proved

sufficient for generating fairly stable patterns of activation for the units in the metrical line.

4. Inputs and results

For example, for the above-mentioned opening to Wordsworth's *Tintern Abbey* I have provided a series of inputs to the system as shown in table 2. Inputs to the system are in increments of 0.1.

The units on the metrical line show no initial inputs, though there is built in a bias for alternate syllables. The intonation is marked by a rise on 'past' and again on 'sum-' and 'length'. For intonation inputs, I established a base of intonation at 0.1, with a rise to 0.2, and a falling contour to 0.0. A lexical emphasis is indicated with an input for lexical stress in any polysyllabic words – in this case 'sum-' (0.1). An input for the prosodic features of the line is placed upon the repeated words 'five'; conventionally I assign a value for alliteration (0.1) and a value for rhyme (0.1), creating a total input value of 0.2. Units representing the main propositions within the text base of the line, 'years', 'past', 'summers', and 'length', receive an input. Words acting as subjects, main verbs, or objects within the main clause receive a value of 0.2; auxiliary verbs or objects in phrases are assigned a value of 0.1. The interpretation of the line seems to me to hang on the balance of 'five years' and 'five summers'; I have supplied an input of 0.2 for units representing those terms as well as for 'length', and an input of 0.1 for the unit representing 'past', another key element to the poem. The system is then sent through thirty cycles to determine the activation of each of the units in the metrical line. The activations of units in the metrical line at the end of 10, 20, and 30 cycles for a typical run cited are seen in table 3.

Each run will yield slightly different results because of the randomness built into the system. Activations for the second run, also shown in table 3, show initially a weaker stress on the opening 'Five', and a slightly stronger

Table 2
Inputs for 'lines'. *0*Five *1*years *2*have *3*past; *4*five *5*sum- *6*mers, *7*with *8*the *9*length.

	Position									
	0	1	2	3	4	5	6	7	8	9
Metrical	0	0	0	0	0	0	0	0	0	0
Intonational	0.1	0.1	0.1	0.2	0.1	0.2	0.0	0.1	0.1	0.2
Lexical	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Prosodic	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
Propositional	0.0	0.2	0.1	0.2	0.0	0.2	0.0	0.0	0.0	0.1
Interpretive	0.2	0.2	0.0	0.1	0.2	0.2	0.0	0.0	0.0	0.2

Table 3
Activations of stress for units on metrical line of 'Five years...'.

Cycles	m0	m1	m2	m3	m4	m5	m6	m7	m8	m9
Run 1										
10	0.4	0.3	0.0	0.4	0.1	0.6	0.0	0.1	0.0	0.2
20	0.8	0.8	0.1	0.7	0.2	0.9	0.0	0.4	0.0	0.6
30	0.9	0.9	0.3	0.9	0.6	0.9	0.0	0.6	0.0	0.9
Run 2										
10	0.1	0.3	0.1	0.3	0.1	0.6	0.0	0.4	0.0	0.8
20	0.6	0.7	0.3	0.6	0.4	0.9	0.0	0.4	0.0	0.8
30	0.8	0.9	0.6	0.9	0.7	0.9	0.0	0.6	0.1	0.9

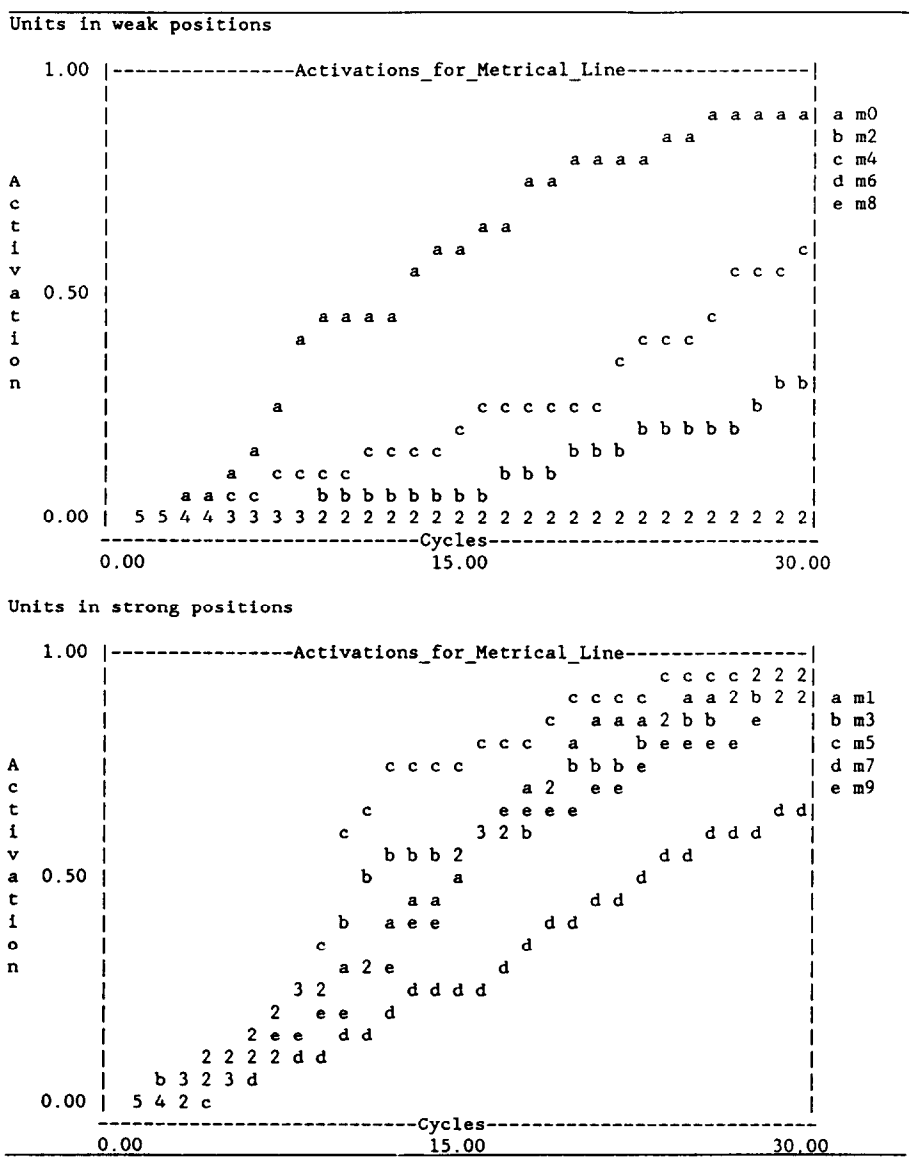
stress on the words 'have' and on the repetition of 'five' in the middle of the line. The activation of each position might be considered as a measure of the amount of emphasis a reader of the line of poetry might give to each individual unit, although the way any particular unit might be stressed will vary. I would here adopt Attridge's (1982) view that stress is the equivalent of the amount of muscular energy that a speaker must use to vary his or her voice to produce for the listener a sense of distinction between one syllable and the next. It appears from both of these runs that the early part of the line shows a greater degree of metrical complexity or tension than the later part of the line, if metrical complexity is assumed to be associated with areas in a line in which adjacent units show strong degrees of stress or in which there is a strong activation of stress in units normally in a weak position.

The activations of these units might also be displayed on a graph. Table 4 shows the level of activation each of the units achieves as it passes through each cycle on a typical run. Letters on the graph indicate each unit in order (ie, a, b, c, d, e for units m0, m2, m4, m6, m8 in the weak position); a number indicates that two or more units have achieved the same activation at that point.

Units in the weak or normally unstressed positions achieve generally weaker levels of activation, except for the unit representing the initial 'Five'. Those in the strong or normally stressed positions all gain activation, with the weakest being the unit representing 'with' and the strongest, 'sum-'.

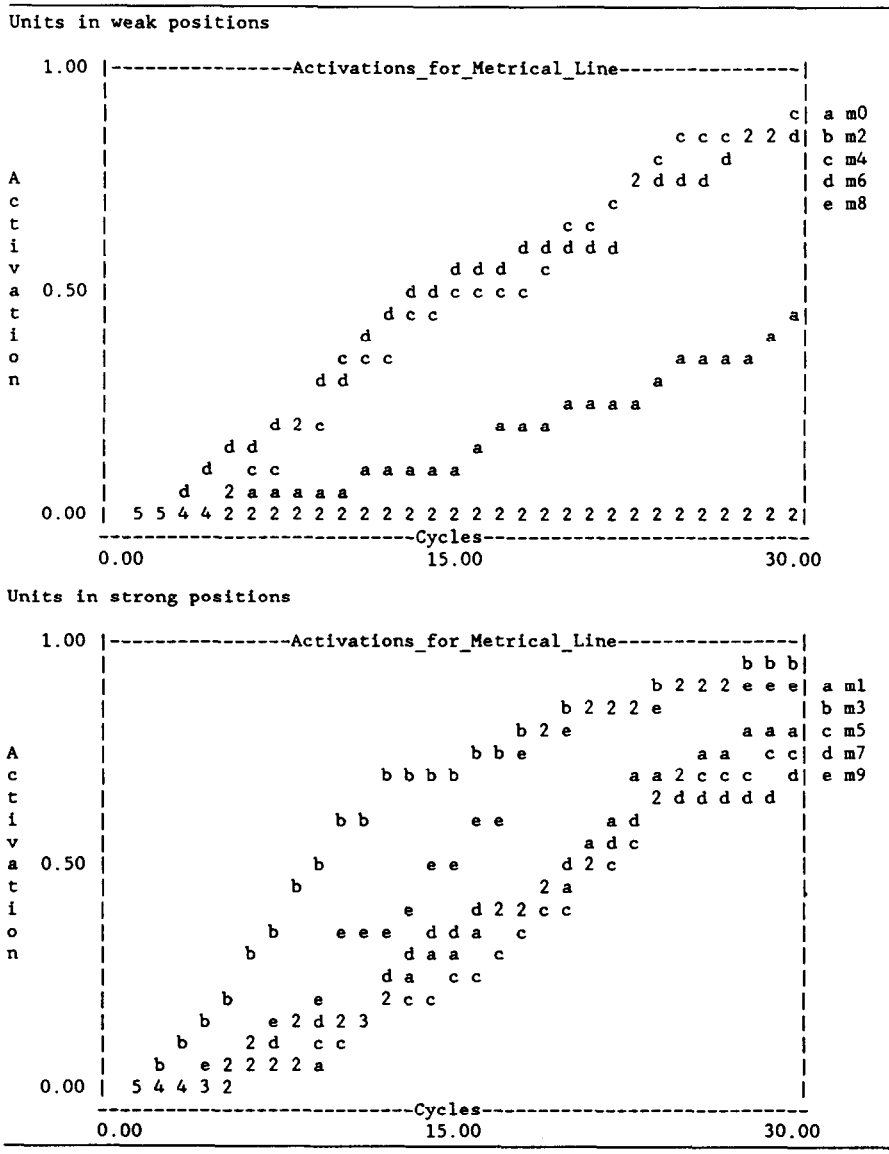
Several results derive from such a model. First, the model creates a measure for metrical complexity or tension arising in performance. Consider, for example, the difference between the patterns of activation of the metrically complex (in fact, by Halle and Keyser's standards, the unmetrical) line by Keats, 'How many bards gild the lapses of time' and those of a metrically balanced and fairly even line by Alexander Pope, 'And sleepless lovers just at twelve awake'. The activations for the units of Keats' line are plotted in table 5, while those for Pope's line are seen in table 6.

Table 4
Activations of stress for units on metrical line of 'Five years...'.



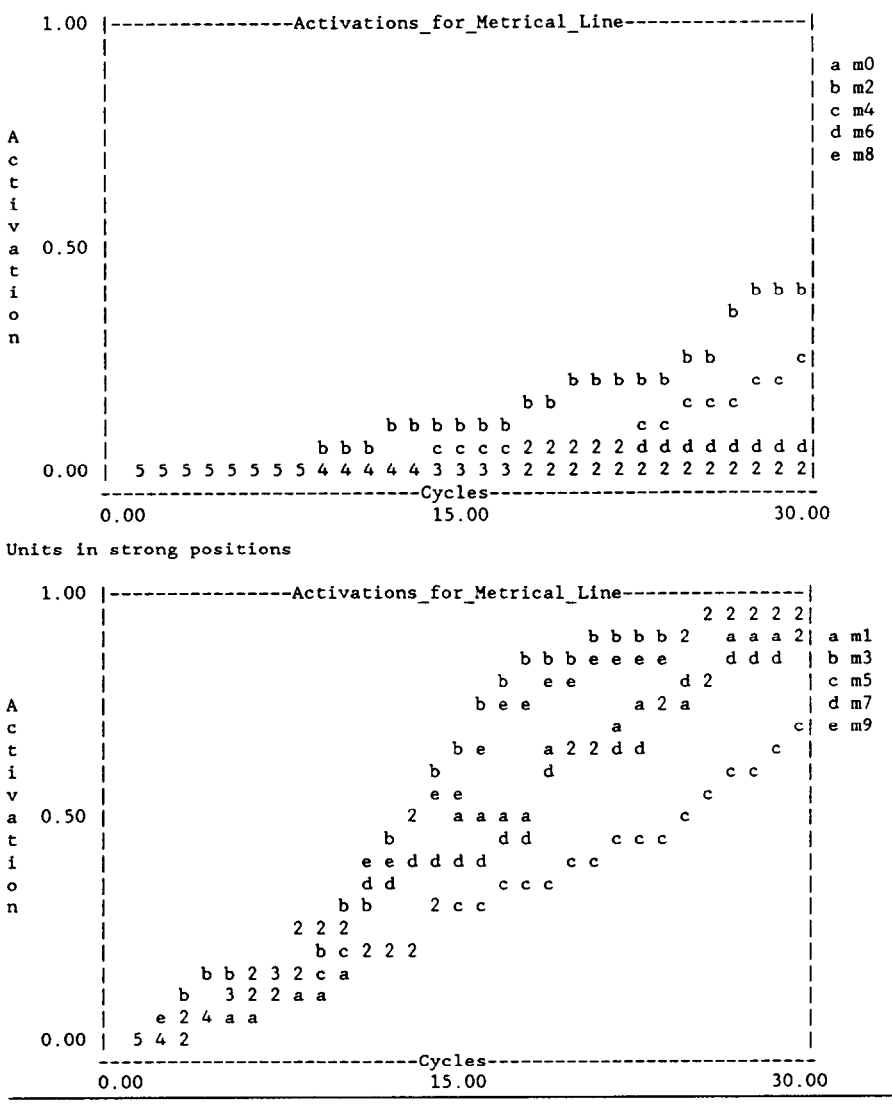
Two of the units in weak positions in Keats' line, 'gild' and 'lap-', achieve activation levels as high as the strong position units. In Pope's line, however, all strong position units in the metrical line achieve much higher levels of

Table 5
Activations of stress for units on metrical line of 'How many bards...'.



activation than those in weak positions. A measure of metrical regularity can be obtained by comparing the total area under the curves – i.e., the total amount of activation over thirty cycles – of the five weak position units to

Table 6
Activations of stress for units on metrical line of 'Sleepless lovers...'.



that of the five strong position units. As metrical irregularity increases, the equation will approach 1.0; a highly regular line will be indicated by a relatively small fraction. For example, the ratio of the activations of units in

normally weak positions to the activations of those in strong positions in the Keats line equals approximately 0.53, while the ratio for Pope's line is approximately 0.13. Initial results of more extended analyses suggest that such measures may be valid for describing metrical regularity; eight lines from Pope's *Essay on Criticism* yield a ratio of 0.21, and eight lines from his *Moral Essay I* have a ratio of 0.23. The first nine lines of Hart Crane's *Rip Van Winkle*, on the other hand, have a ratio of 0.34, confirming a subjective impression of a greater metrical irregularity in Crane's poem.

5. Implications for future research

The connectionist model of poetic meter may also be used to describe different performances of a line of poetry due to varied interpretations of the poem. The model accomplishes this by varying initial inputs to the system in accordance with the importance assigned to particular units. Similarly, it may be used to model different types of reading, allowing a strengthening of the weights of the connections between, for example, the prosodic units and the metrical units, to emphasize the prosodic effects. Increasing the bias of the units in normally strong positions would create the kind of sing-song effect teachers use to first describe iambic rhythm; decreasing or eliminating the bias and/or the negatively weighted connections between adjacent units in the metrical line would develop a flatter, more prosaic rhythm. In these ways, the model is useful for describing the ways in which poetry is actually spoken or read.

In summary, a connectionist model of poetic meter addresses some areas of interest to those concerned with metrical analysis. The connectionist model described here provides a description of possible performances of a line of iambic pentameter poetry. Varying the weights between connections and initial inputs will cause a variation in the activations of the units associated with metrical stress. The model may also be used to describe a range of possible performances varied by interpretations on the part of the reader. I have also suggested that the model may be used to describe metrical complexity through measurement of the activation of adjacent units in the metrical line and through measurement of the ratios of activations of alternate units.

A connectionist model has the potential for use in future research in addressing several significant questions. Are particular metrical contours associated with particular poets? Do activation patterns for individual units on the metrical line take on characteristic shapes? Do individual poets tend to exhibit ranges of metricality as measured by this model or do their lines stay fixed within particular limits? Are there activation patterns associated not just with individual poets but with particular periods or genres? Such

questions are, I believe, interesting for understanding the nature of poetic meter and its performance.

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