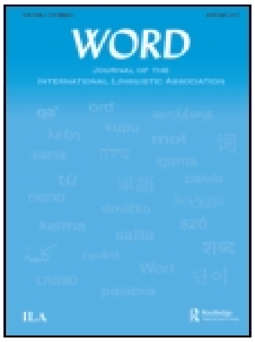

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The Cluster Matrix and Vowel and Consonant Distribution*

The vowel/consonant dichotomy has an ancestry as old and respectable as that of the study of language itself. Yet the difficulties involved in achieving a satisfactory definition in terms of articulatory features (most commonly aperture) and acoustic ones (most commonly resonance) are well known, and it is not surprising that twentieth-century linguistics has brought into play what it once fondly imagined was its ultimate weapon—distribution. In particular, the British phoneticians O'Connor and Trim attempted in an article published in *Word* in 1953[1] to arrive at a definition of *consonant* and *vowel* based on the concept of distributional similarity. The principle was simple: in a group of n phonemes we find that phoneme a turns up in words adjacent to, say, 75 percent of the phonemes which occur adjacent to phoneme b, while environments it shares with c represent only 24 percent of the total distribution of the latter. If we compare pairwise all the items in our inventory (as provided by the phonemicist), we shall eventually establish two classes within which the similarity index is high (say, over 50%), but between which it is low (say, less than 50%).

I have suggested in discussion that if similarity of the type envisaged is to be our operative factor, it can be shown that absolute agreement yields more satisfactory results than positive agreement; that is, we should consider not only the environments which two phonemes share but those from which they are excluded. The proposal presented here is quite unrelated to similarity measures of class membership and is in fact grounded in the belief that the sharing of environments is an incidental consequence of another and more fundamental characteristic of vowel and consonant distribution—the tendency of vowels and consonants to collocate.

* A modified version of the first half of this paper was read on March 18, 1967, at the Twelfth Annual Conference on Linguistics sponsored by the Linguistic Circle of New York.

1 J. D. O'Connor and J. L. M. Trim, "Vowel, Consonant, and Syllable—a Phonological Definition," *Word*, IX (1953), 103–122.

Although O'Connor and Trim operate in terms of triangular matrices whose cells register a common context measure for the pair of phonemes whose row and column intersect there, the facts can be represented more conveniently for comparative purposes in terms of the traditional cluster matrix and, as I shall show later, a network associated with it. However, the network directly implied by the similarity approach can be represented as in chart 1 and is derived from a pairwise comparison of the entries in the lines and columns of the hypothetical cluster matrix of chart 2.

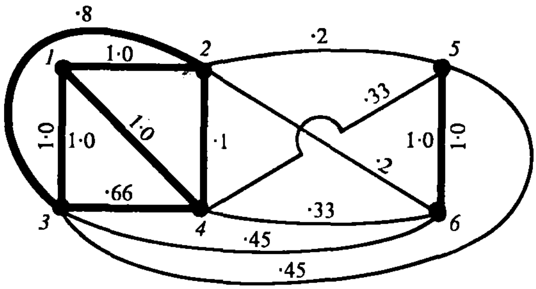

CHART 1. Similarity network for L

		1	*2*	*3*	*4*	*5*	*6*	
A	*1*					+	+	B
	2					+	+	
	3				+	+	+	
	4		+	+		+	+	
C	*5*	+	+	+	+			D
	6	+	+		+			

CHART 2. Associated matrix

The actual computation is performed for any pair of phonemes *a* and *b* by summing their shared "successors" and "predecessors" and dividing this sum by the total number of successors and predecessors of the phoneme with the smaller total distribution. For instance, reading across the matrix, it can be seen that elements *3* and *4* share two successors (*5* and *6*), and reading down, two predecessors (again *5* and *6*). The total distributions of *3* and *4* represent *6* and *7* respectively, so that the required fraction is 4/6 or .67. Note that in cases where two classes as described in the first paragraph can in fact be easily established, the matrix associated with the similarity network will contain four sharply delineated blocks; one pair of diametrically opposite blocks will be densely populated and the other pair relatively empty. If we arrange the phonemes in order of increasing total distribution from left to right and from top to bottom, the dense blocks will be at the top right-hand and bottom left-hand corners (blocks B and C) and will represent the intersection of unlike elements (i.e., vowels and consonants); they will be referred to as the "heterogeneous" blocks.

The model is topologically similar to the one set up by Bloomfield[2] to represent the density of communication within linguistic communities. Within villages (the left and right sets of nodes), we have a condition of steady hum (links are thick and numerous), while inter-village contact is spasmodic (links between the sets are thin and sparse). As applied to vowel and consonant distribution, the model is complex in two main ways: (1) the method requires a link between every pair of nodes (with the rare exceptions where pairs of phonemes have no common contexts, e.g., English /h/ on a "naive" analysis) and the velar nasal [ŋ], and (2) the links are of a thickness representing degrees of similarity which can vary from $1/n$ to 1, where $n =$ the number of phonemes in the inventory. It is suggested that a network of this type is more complex than the facts which it purports to handle and that the concept of similarity on which the method is based does not correspond to our intuitive notions of the vowel/consonant dichotomy. If we were to establish a male/female dichotomy by studying the dating practices of young people within a small but fairly promiscuous community, there is no doubt that one way of setting about this would be to observe the moviegoing pairings-off which occurred over a period of time; there would presumably be considerable agreement between any two members of the same sex as to choice of mates; yet this method of approach is clearly indirect. Would it not be preferable to start from the incontrovertible fact that boys on the whole prefer girls, and vice versa? Vowels occur adjacent to consonants more readily than they do to one another. That consonants occasionally cluster together is a fact which we should seek to ignore insofar as, while they may display similar clustering patterns within the consonant system (English stops all precede /r/), this agreement is not a badge of consonantality as such; only clustering with vowels indicates that. We will therefore link not pairs of phonemes which agree in choice of partners but those which in fact partner one another, and what we shall seek to measure will be the "attraction" or "valency" which juxtaposition implies, seeking to discount as far as possible the effects of homogeneous clustering. The essential attribute of a consonant is to precede and to follow any vowel and of a vowel to return the compliment. If we simply link elements which occur in sequence, we obtain the graph (attraction network) of chart 3. Note that, instead of links of varying thickness, we

[2] Leonard Bloomfield, *Language* (New York, 1933), pp. 46–47.

have simple unoriented arcs and that elements are not linked at all unless they actually occur in sequence within utterances. The binary partitioning is done in such a way as to set a maximum value on the number of arcs linking the subsets. In this case the cross-links total 8, while there are only 2 side-links (in an unoriented graph of this type, temporal ordering cannot be represented so that pairs of sequences reflecting one another such as *3–4* and *4–3* are shown by a single arc).

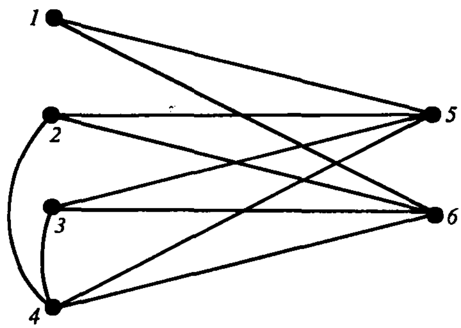

CHART 3. Attraction network for L

Detailed discussion of the procedure for reaching the particular position which will provide maximum cross-linkage would be out of place; it is, however, easy to see that in simpler cases a rough and ready method will yield the correct solution. We can group the elements in random order (round a circle for convenience) and then "pull over" to the right those linked by the highest number of arcs (in this case, *4*, *5*, and *6*, which have four links each; see chart 4). We then ask whether any further trans-

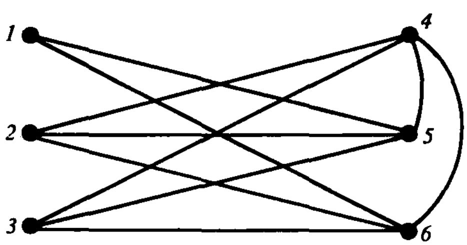

CHART 4. Network rearranged

ference in either direction would result in an increase in cross-linkage value. Obviously such cases would only arise where an element has more side-links than cross-links. Elements *1*, *2*, and *3* have no side-links at all and are accordingly left where they are; *5* and *6* have three cross-links but only one side-link and are again left alone; *4*, though, has the same number of each, and its transference back to the left would leave the cross-linkage unaffected. A glance at the associated matrix (chart 5) shows the meaning of this analysis:

	1	*2*	*3*	*4*	*5*	*6*
1					+	+
2					+	+
3				+	+	+
4		+	+		+	+
5	+	+	+	+		
6	+	+	+	+		

CHART 5. Matrix rearranged

4 clusters with as many homogeneous elements (*2*, *3*) as it does with heterogeneous ones (*5*, *6*); the effect of transferring *4* back to the left on the network would correspond on the matrix to the shifting of the dotted lines which demarcate the blocks one position to the right and bottom (to yield the arrangement of chart 2). Now the latter partitioning is intuitively more plausible, for it implies a language in which all combinations of vowel and consonant are implemented and which permits in addition three homogeneous two-member clusters. The system implied by chart 5, however, corresponds to a language in which a certain phoneme (*4*) fails to occur in half the theoretically possible heterogeneous clusters; for instance, if *4* corresponded to a vowel, there would be a restriction against its occurrence before one and after two consonants, and it would indeed be the only vowel which could not occur with all consonants. It is therefore apparent that the CV and VC blocks of the cluster matrix should be characterized not only by the number of entries (cross-links on the graph) but also by density (percentage of occupancy). Consequently, it is proposed that the maximum we are looking for should represent the product of the total number of cross-links and the density, the latter being given as actual cross-links divided by potential ones. Potential cross-linkage is calculated quite simply by multiplying together the membership of either set; thus, if element *4* is on the right (as in chart 4), we have a possible total of 3×3 cross-links, while if it is on the left, the figure is 4×2. The maximum score possible under our revised formula is thus attained by arranging elements *1*, *2*, *3*, and *4* on the left (as in chart 3), giving us a score of $8 \times 8/8 = 8$.

It is suggested that the decision made by this procedure reflects our intuitive feeling that the essential distributional attribute of a consonant as opposed to a vowel is occurrence in sequence with vowels; thus, it purports in fact to be an explicit and operational definition of σύμφωνον (or its Latin calque, *consonans*) 'sounding together with' (sc. a vowel). One of the advantages of relating actual to potential cross-linkage and the consequent introduction of fractional values for the linkage score is that the chance of multiple maxima is virtually eliminated. The occurrence of twin maxima is possible only in the very rare conditions in which the relevant equation has solutions within the natural number system.[3]

We have up to now treated contiguity of phonemes without reference to the time dimension. It is, however, clear that the cluster matrix provides information in addition to that implied in an attraction network: its cells represent *ordered* pairs of elements. According to the normal convention, the element located at the intersection of row i and column j represents the sequence i–j in that order. Now in many cases we shall get the same result whether we work with an attraction network or with a matrix. This would apply, for instance, with languages such as Japanese or Samoan which have no or few consonant clusters. If we take a hypothetical cluster matrix for a language of the Samoan type (see chart 6), we note that the triangle above the main diagonal is an exact reflection of the one below it and that,

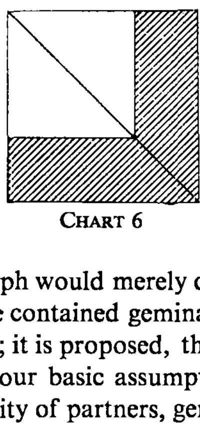

CHART 6

therefore, the associated graph would merely duplicate every arc (ignoring orientation). If the language contained geminate vowels, then the network would contain simple loops; it is proposed, though, that geminates be left out of consideration. For, our basic assumption being that collocability characterizes the heterogeneity of partners, geminates can provide no rele-

[3] The equation is $\frac{x^2}{ab}=\frac{y^2}{(a+1)(b-1)}$, where a = number of elements in set to which transference is made, b = number of elements in set from which transference is made, and x and y = cross-links before and after transfer. The solution set for this Diophantine equation appears to be $a=1$, $b=9$, $x/y=3/4$; $a=4$, $b=81$, $x/y=18/20$; $a=8$, $y=50$, $x/y=20/21$. Thus, in an 85-phoneme system, if we have four elements on one side, the transference there of one element would change the potential cross-linkage from $4\times 81(18^2)$ to $5\times 80(20^2)$, so that in cases where x and y were in the proportions 18:20 the equation would be satisfied.

vant information; that elements belong to the same class as themselves is true but unhelpful. Clearly, the duplication of every arc cannot in any sense affect our computations: we are merely doubling each side (i.e., the scores before and after any transfer). However, while it is true in general that there is a VC sequence corresponding to every CV one (so that the VC block of a matrix can be obtained by reflecting the CV block about the main diagonal), it is certainly not true in general that if a certain consonant cluster occurs, so does its reflection, nor would it seem normal for vowel clusters to occur in symmetrical pairs except when the VV block is full. Indeed, we may take it as characteristic of homogeneous clusters that they occur in only one order: English has /nd/ and /ft/ within morphemes but not their reflections. As a theoretically minor modification, but one with considerable empirical consequences, it is proposed that the attraction network be brought into line with the cluster matrix by allowing as many as two arcs to link a pair of elements. The isomorphism would be complete were the arcs oriented (an arrow pointing from *a* to *b* corresponding to an entry in row *a*, column *b* of the matrix). However, applications made so far indicate that while the occurrence of both *ab* and *ba* is typical of heterogeneity, no use can be made in general of the fact that where only one occurs it occurs in that particular sequence. We therefore omit arrows and ignore the temporal ordering indicated by the matrix (i.e., we treat the square matrix as if it were folded about its main diagonal and the entries summed).

The O'Connor and Trim procedure was based on the two-member clusters which occur word-initially and word-finally (in English). This restriction may be justified empirically on various grounds. In particular, there is the general, if not universal, characteristic whereby restrictions on consonant clusters may most easily be described in terms of the syllable and which reflects the well-known fact that medial consonant clusters tend to be more numerous than initial or final ones. Turkish, for instance, if we exclude such borrowings as *plân* and *flört*, lacks word-initial clusters and word-finally severely limits them (*dört* 'four', *aşk* 'love'); yet medially we find a wide range, across morpheme boundaries (*kaldı* 'he stayed') and intramorphemically (*eski* 'old'). It would seem, furthermore, common for initial and final orderings to reflect one another in cases where the same pair of phonemes occurs at all in both positions. Thus, /tr/ occurs initially in English and /rt/ finally (at least in some varieties), and in Serbo-Croat the apical trill succeeds a wide range of initial consonants and precedes a wide range of final ones. We therefore further increase the links connecting a pair of elements to a potential 4, such that any pair of phonemes will score up to twice initially (e.g., English /m/, /i/ in 'mitt', 'immoral') and up to twice finally ('Tommy' 'him'). It is, of course, true that certain languages have a general prohibition against final VC sequences, so that the total possible score for heterogeneous clusters is brought down to 3. But such languages (possibly always) exclude final consonant-clusters and are likely to be short or initial ones: Zulu forbids consonants finally, but it also lacks both final and initial consonant clusters (typical items are *pʰuza* 'drink', *kʰuluma* 'speak', and *inja* 'dog'). Similarly, languages which exclude initial VC (e.g., Classical Arabic) will presumably lack initial VV. Thus, the density differential between the heterogeneous and the homogeneous blocks of the matrix will in general be maintained: any reduction in the maximum score per cell in the VC and CV blocks (or in the cross-linkage maximum per pair of elements in the network) will be accompanied by a corresponding reduction in the CC or the VV block (or in the side-linkage), or both.

This, then, is the procedure. Its aim is to set up a binary partitioning of objects from a given set whose sequential constraints are known, such that combinatory latitude between the subsets is maximized. Its operation can be illustrated in terms of an attraction network or a matrix. The former is more graphically indicative of its relation to the phenomenon measured (attraction between classes of objects), but is visually confusing. Instead, an illustrative operation is performed on the cluster matrix of Cypriot Greek (see table 1).[4]

TABLE 1. CYPRIOT GREEK INITIAL AND FINAL CLUSTERS

	ž	γ	θ	δ	x	z	š	y	v	f	č	l	k	m	ḳ	t	r	p	s	n	u	i	e	o	a
ž																					2	1	2	2	1
γ												1					1			1	2			2	2
θ															1						1	2	2	2	2
δ																	1				2	2	2	2	2
x																1					2	2	2	2	2
z														1							2	2	2	2	2
š							1														1	2	2	2	2
y																					2	2	2	2	2
v												1					1			1	2	2	2	2	2
f													1		1	1					2	2	2	2	2
č											1										2	2	2	2	2
l																					2	2	2	2	2
k							1					1	1				1		1		2			2	2
m								1						1				1		1	1	2	2	2	2
ḳ															1						2	2	2	2	2
t																	1		1		2	2	2	2	2
r													1								2	2	2	2	2
p												1			1		1	1	1	1	2	2	2	2	2
s													1		1	1		1	1		2	2	2	2	2
n								1			1					1				1	2	2	2	2	2
u						1					1	1				1	1		2	2		1		1	1
i	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2		1	2	1	2
e	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	1	2	1	2	1
o	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	1	2	1	1	1
a	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	1	2	2	1	1

[4] For a fuller discussion of Cypriot Greek, see my "The Phonology of Cypriot Greek," *Lingua*, XVIII (1967), 384–411, and "Cypriot Greek: Its Phonology and Inflections" (forthcoming).

The first step is to list the two-member combinations which occur initially and finally in words and to plot these on a joint matrix with the phonemes arranged from left to right and from top to bottom in order of increasing total distribution. A *2* indicates occurrence both initially and finally, and a *1*, occurrence in either one position or the other (in Cypriot Greek mostly, in fact, initially).

We then block off the cell in the bottom right-hand corner and evaluate the formula x^2/y for the rectangle above it (the "B block") and the rectangle to the left of it (the "C block"), where x is the sum of entries and y, the potential sum. Thus, in this case block B has 24 cells with a total of 44 entries out of a potential total of 48, and the corresponding figures of the C block are 28 out of a potential 48. The required value is thus $72^2/96$, or 54, to the nearest integer. We then move one position up the main diagonal so as to block off the square ("D block") formed by the intersection of the last two phonemes and compute the value of x^2/y for the new B and C blocks thus formed. We continue to move up, blocking off larger and larger squares, until our formula attains its maximum value, at which stage we assume that the B and C blocks represent the intersection of heterogeneous phoneme classes; that is, the point which we have reached along the rows (and, ipso facto, columns) represents the point of division between consonant and vowel. The figures for the first seven positions are given in table 2 and show that the point of division lies between the phonemes which are sixth and fifth from the right. The decrease which sets in at that point is found to continue until the whole matrix has been blocked off.

TABLE 2. VALUES OF x^2/y

Phonemes Traversed	Entries in B and C (x)	Potential entries (y)	x^2/y
1	72	96	54
2	140	184	107
3	197	264	147
4	244	336	177
5	284	400	202
6	271	456	161
7	258	504	132

If the operation were performed in terms of the associated attraction network, the procedure would be logically equivalent. The phonemes are in that case represented by vertices and the entries in the matrix by links. Vertices are "pulled over" to the right in decreasing order of the number of arcs connecting them, and x^2/y is computed by squaring the number of cross-links and dividing by the total possible—this being arrived at by multiplying the number of vertices on one side by those on the other and this again by 4 (the maximum linkage possible between any two vertices).

The methods described can be relied upon to establish a binary partitioning of the phonemes of a language from a phonetically unspecified list of the two-member clusters into which they enter initially and finally. Such a partition corresponds in the cases investigated so far to the traditional classification into vowels and consonants. Two questions occur: (1) How would the method handle the case of languages for which a trichotomous classification is regarded as appropriate? (2) Can it in itself indicate which of the two classes defined by it represents the vocalic and which the consonantal elements?

With regard to the first question, we are not here concerned with the phonemicist's techniques; we can merely accept his conclusions on trust and operate on his data according to the procedures laid down. Now classes other than vowel and consonant are normally set up to account for the occurrence of peak satellites, and we may take the exhaustive listing of possibilities provided by Hockett[5] as a convenient basis for discussion. The most obvious difference between the criteria used in identifying satellites and those we allow ourselves in establishing our own dichotomy is that, while we limit ourselves to consideration of two-member clusters, the label *satellite* will normally involve consideration of both flanking elements (including possibly silence). Thus, the account in Kučera's *Phonology of Czech*[6] respecting the distribution of Czech [i̯], [j], and [i] involves such observations as that [i̯] (the "non-syllabic variety" of [i]) occurs "after short and long vowels . . . before disjuncture or consonant" and that [j] occurs "between vowels." A two-dimensional matrix is obviously incapable of expressing such facts and many similar ones (such as that Southern Slavic [r] is vocalic between consonants). The phonemicist discovers and describes the facts; our present purpose is merely to show that objects arranged in varying sequences can be assigned to two distributional classes on the basis of their two-member clustering characteristics. Clearly, therefore, we are incapable of setting up the various categories of ambivalent elements which phonology finds useful; such "hermaphrodites" will be assigned willy-nilly to one class or the other. It is impossible to state without detailed examination of each individual case where "intermediate" classes will be placed, but we may posit the simplest possible case and observe the results. Let us assume that *satellite* means 'occurring after

[5] Charles F. Hockett, *A Manual of Phonology*, Memoir 11, *International Journal of American Linguistics* (=XXI, No. 4, Part I [1955]), p. 75.

[6] Henry Kučera, *The Phonology of Czech* (The Hague, 1961), p. 28.

all vowels and before all consonants', *nucleus* implies 'before and after every consonant', and *margin*, 'before and after every vowel' (vowels and consonants having been already grouped, and, to simplify this account, labeled). It can be shown that our attraction network method will give results for Hockett's classes as shown in table 3.

TABLE 3

	Hockett's Classes			Matrix Entries				Network Decision
	Nu-cleus	Sat-ellite	Mar-gin	C-	-C	V-	-V	
Vowel	x			x	x			V
Covowel		x			x	x		V
Consonant			x			x	x	C
Semivowel	x	x		x	x	x		V
Demivowel	x		x	x	x	x	x	V
Semiconsonant		x	x		x	x	x	C
Omnipotent	x	x	x	x	x	x	x	V

The question whether an attraction network as described above can, in addition to setting up two distribution classes corresponding to vowel and consonant, label the classes correctly would seem to be that in itself, without benefit of collateral information, it is incapable of this. This is at first sight surprising. In the early stages of work on the present topic, I asked a Japanese colleague[7] to prepare a cluster matrix of Japanese with the phonemes identified by number and arranged in random order. The most obvious feature of the matrix turned out to be five practically continuous rows with five columns at corresponding points, so that by simply moving these to the bottom and right respectively a matrix was obtained in which blocks B, C, and D were almost completely occupied and A almost empty (cf. chart 6). As the occupied blocks were five entries across, the immediate conclusion was that the last five phonemes were vowels. A moment's consideration will convince one, though, that such a conclusion relies on the additional information that in Japanese vowels are less numerous than consonants and that in general at least some sequential restrictions operate within consonantal systems. Yet a system with x vowels and y consonants can be shown to be isomorphic, with one containing y vowels and x consonants. To illustrate this, let us take the ultra-simplified case of a language with four consonants and two vowels, such that all heterogeneous but no homogeneous clusters occur. The unordered

[7]Information from Maya Koyzumi.

matrix would appear as in chart 7. Entries occur at the intersection of heterogeneous rows and columns. It is thus clear that, if, instead of two vowels, we had four, the matrix would be identical in appearance.

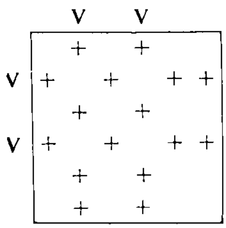

CHART 7

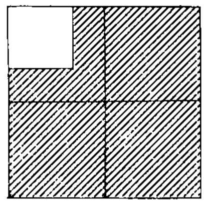
CHART 8

It may be asked under what circumstances the procedures outlined would give a result at variance with a vowel-consonant dichotomy established on more usual grounds. First of all, it may be noted that in a language with no homogeneous clusters, the correct decision will be given no matter what the proportion of vowels to consonants. Thus, if we consider a matrix with full B and C blocks but empty A and D ones, it is clear that the maximum value of x^2/y will occur at the correct point; for a point which yields full B and C blocks and empty A and D ones clearly sets a maximum value on x, and—as all possible clusters are implemented in A and D—x will equal y, so that $x^2/y\,(=x)$ will be at its maximum. It is not, however, such cases (which are transparent on casual inspection anyhow) which are likely to suggest queries so much as those in which the homogeneous blocks are partially or completely filled:

1. One homogeneous block is completely filled, the other completely empty. This situation would seem to arise in Samoan, which allows all vowel clusters but no consonant clusters. Now provided that the homogeneous block which is full is smaller than or equal to the empty one, it can be shown that the method will yield the same decision as it would were both homogeneous blocks empty. For, if we employ it on a Samoan-type language (see chart 6), we find that as we move along the main diagonal from the bottom right-hand corner, we establish VC and CV blocks of increasing size and, as long as they are full, ipso facto an increasing attraction score. When we reach the point of cleavage between vowel and consonant, our maximum is attained, and from then onwards, as y continues to increase, x diminishes. If, however, the full homogeneous block is larger than the empty one, our maximum score will be reached at the point halfway across the matrix (see chart 8). I do not know of such a language, and there may be some universal law related to redundancy which prevents its

occurrence. Such a case would imply, for instance, that of the $2n^2$ two-member clusters possible on a joint matrix of initial and final positions, over 50 percent in fact occur, and this would seem to be at least rare. Serbo-Croat, according to my computation, scores 47 percent, but its exploitation of capacity seems to be higher than the average. The corresponding figure for Cypriot Greek (with all vowel chains in at least one position and with various consonant clusters initially) is 28 percent, and for Turkish (with very few homogeneous clusters, but eight vowels vs. twenty consonants at least), 36 percent.

2. The larger homogeneous block ("A" if the elements are arranged in order of increasing total distribution) is partially occupied; if we assume again that the heterogeneous blocks are full, our progress up to the point which divided the full blocks from the partially filled one will be the same as if it were empty insofar as entries are not considered until we reach the row and column in which they lie. This is perhaps the commonest case.

Assuming that the point we have reached has established full B and C blocks of maximum size (i.e., that all unambiguously heterogeneous clusters have been included in these panels), what sort of densities would entail further inclusions? To take a concrete example, if we assume that Serbo-Croat[8] permits all CV and VC clusters in initial and final position (and this is perhaps the case if we include certain borrowings, such as *gitara* and *geto*), and that in moving across the matrix we have taken in the five vowels, what total distribution within the A block must the next most widely distributed phoneme have in order to qualify for addition to the heterogeneous blocks? On one analysis of Serbo-Croat there are, in addition to the five vowels, 25 consonantal elements and of these latter /r/ is the most widely distributed, with a total of 26 positions in addition to the 20 before and after vowels. Thus, the "score" at the actual point of cleavage is given as the square of the actual entries in B and C divided by the total possible entries in B and C (i.e., $500^2/500 = 500$). If one further move along the main diagonal is made, the total cells will increase in number to $6 \times 24 \times 2 = 288$, with a capacity of 576, while the new total entries can be obtained by adding to 500 the A-block entries of the next most widely distributed phoneme and deducting the 20 B- and C-block entries whose loss is entailed by a move. Thus, if z represents the number of entries qualifying for inclusion, $(500 - 20 + z)^2/576 = 500$, or $z = 57$. The facts are represented schematically in chart 9. Fifty-seven represents a .59 fraction of total potential entries

[8] See Milan I. Surdučki, "The Distribution of Serbo-Croatian Consonants," *Slavic and East European Journal*, VIII (1950), 159–181. Help from D. Jurisič is also acknowledged.

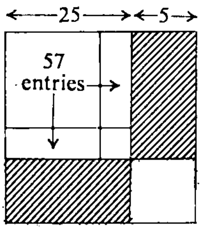

CHART 9

(i.e., 57/24 × 2 × 2, the cell on the diagonal being ignored). It can be shown that the required fraction is a function of the proportion of phonemes already traversed (in this case 1/6) and varies only slightly with inventory size. The graph (see chart 10) illustrates the characteristics of the relevant curve and is plotted for an inventory of 40. It can thus be seen that the method gives a correct result for Serbo-Croat, a language with complex consonant-cluster patterns. A Serbo-Croat consonant would require 57

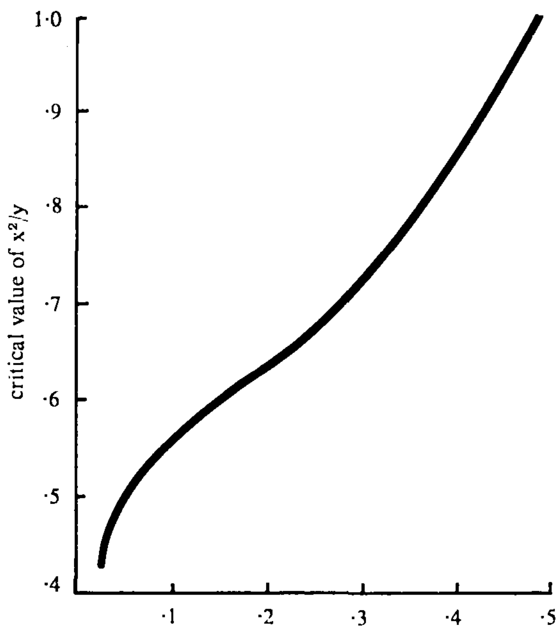

CHART 10. Proportion of matrix traversed

entries in the A block of the joint matrix for admission to the heterogeneous blocks (as a "vowel"). The highest frequency found, however, is 26.

Apart, therefore, from a consonant clusterability more complex than that of Serbo-Croat, there would seem to be one situation likely to throw our method out of gear, so that it partitions phonemes in a manner clearly inconsistent with our intuitions: our basic assumption that the essential attribute of members of either major class is to cluster with members of the other may be invalid in that languages occur with a clearly defined vowel-consonant contrast and yet embody extensive constraints on vowel-consonant combinations. The case of general prohibitions against CV or VC clusters in terms of initial or final position was shown to be no impediment to the operation of the method. More worrying are (1) systematic restrictions on particular combinations of vowel and consonant, and (2) accidental irregularities arising from the general rarity of particular consonants or vowels. Both types of restriction are found in Cypriot Greek. The velar consonants [k] and [γ] do not occur before front vowels (being replaced morphophonemically by [č] and [y] respectively), and it may also be noted that [u] is "accidentally" rare initially before consonants. Such restrictions, if sufficiently severe, could result in misassignment in two ways:

1. If the overall density of the CV and VC blocks is less than 100 percent, there will be a corresponding reduction in the critical values of x^2/y. It can in fact be shown that the critical densities above which A-block elements will be included in the B and C blocks are reduced in direct proportion as the densities of the latter blocks fall short of 100 percent. Thus, in a language with 50 percent occupancy of the CV and VC blocks, the number of entries in the next most dense row and column of the A block which would qualify for inclusion in B and C would be halved. A preliminary inspection of natural languages suggests, however, that heterogeneous block densities are rarely, if ever, low enough to reduce CC block critical scores to a level at which misassignment of consonants would be possible.

2. The frequency of a particular vowel may be so low that it does not attain the critical density required for inclusion in the B and C blocks. This contingency could arise through the existence of systematic restrictions of an assimilatory nature on combinations of vowel and consonant or accidentally through the relative overall rarity of a phoneme. Note that low overall density in itself cannot result in this type of misassignment, as may be shown by observing extreme cases.

Chart 11 represents a language in which half the consonants occur before and after only half the vowels (and phonetic disparities are such as to deter the most ardent complementationists); it may be seen that the resultant chess-board effect, although halving all values of x^2/y, would produce no shift in the actual position of the maximum, for the density of the rows and columns as they are progressively taken in remains stable at 50 percent. Similarly harmless to our procedure would be a language which had an initial/final partitioning of consonants (cf. Mandarin).

Chart 12 depicts an extreme case. The situation is exactly as if no

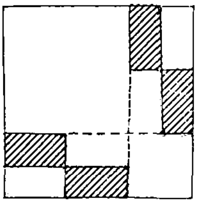

CHART 11

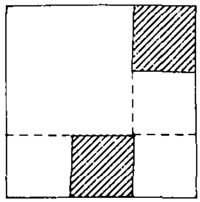

CHART 12

final consonants were allowed, for by folding the matrix about the main diagonal, we get the same pattern as would result from performing the operation on a matrix with no C block but a full B one.

It is, however, possible to conceive of cases where a frequency drop occurs within what are in fact the heterogeneous blocks of the matrix which is such as to produce a reduction in the x^2/y score before the real point of demarcation is reached. Such would be the case if, while the last n vowels of a language were relatively widely distributed so as to yield dense rectangles, the vowel next in frequency had accidental or systematic restrictions on its occurrence adjacent to consonants, such that the density of its row and column did not reach the critical value. If, for instance, not only /y/ and /k/, but a total of half the consonants of Cypriot Greek were excluded from occurrence before front vowels, then clearly their columns in the CV block would have only a .5 density, and, as we saw earlier (chart 10), this would not qualify for grouping in the heterogeneous blocks once .1 of the matrix has been traversed. On the other hand, such a restriction, to be fatal, would have to be repeated in the VC block, whereas we may presume that in most cases restrictions on successors are not paralleled by those on predecessors. As to accidental restrictions of this type, may we note that the rarity of /u/ in initial position in Cypriot Greek is counteracted by its wide distribution finally (because of its occurrences as the unique segmental material of two suffixes, one meaning 'genitive singular masculine' and the other [stressed] 'feminine diminutive'). However, cases are certainly conceivable of a vowel so rare as to have a frequency within the A block (as established at a given point in our procedure) too low to justify inclusion in the B and C blocks.

One thinks particularly of recent borrowings (nasal vowels in some renditions of English), contractions (Arabic /o./ and /e./ < /aw/ and /ay/, and indeed Modern Greek /u/) or recent contrast arising from phonemic split (British English /ʌ/ : /u/). If such cases prove in fact to be widespread, it should be possible to incorporate certain safeguards into our procedures—for instance, automatically to reject from the A-block phonemes which would otherwise appear as unique cluster formers, or perhaps better to check results against a three-dimensional matrix so that phonemes regularly flanked on both sides by a relatively wide range of consonants could be accepted as vocalic in spite of their overall rarity. The alternative, of course, is to treat counterinstances as fatal to the whole notion that methods of the type proposed can be of general validity—in which case it is merely one more nail in the distributionalist coffin.

The procedure outlined above in the discussion of the matrix of Cypriot Greek will probably set a maximum value on x^2/y in the majority of cases, although ideally the operation would be computerized so that all phoneme partitions possible could be measured for cross-linkage. That the initial ordering was made to depend on total distribution of elements, while eligibility for inclusion in the heterogeneous blocks is based on occurrence elsewhere than in these as constituted at a particular moment, implies the possibility of the need to reshuffle in either direction: (1) It could happen that when the maximum value is attained, there is an element at present removed more than one position to the left, which has a proportion of entries in the A block qualifying it for inclusion in B and C. An example is provided by the vowel of Standard English *bull* and *good*, which has a total distribution considerably more restricted than that of certain consonants. Schematically, we have the situation depicted in chart 13.

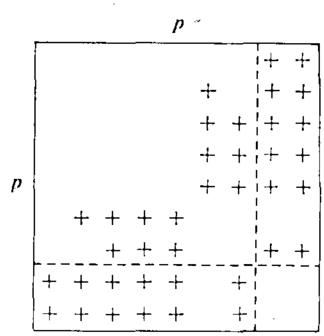

CHART 13

Because phoneme *p* occurs irregularly, if at all, in the B and C blocks as they are at this stage depicted, its total distribution is less than that of elements to the right, which implies that, when the apparent maximum is attained, elements to the left must still be scanned for frequencies within the present A block warranting addition to the heterogeneous blocks. (2) At least one possibility can be conceived which would entail movement in the converse direction. Let us assume, for the sake of the argument, that initial and final matrices are identical and internally symmetrical, so that by dividing the entries by 4 and presenting the upper triangle half of the matrix, the data would be accurately represented as in chart 14.

	a	*b*	*c*	*d*	*e*	*f*	*g*	*h*
a					1	1	1	1
b					1	1	1	1
c					1	1	1	1
d					1	1	1	
e								1
f								1
g								1

Chart 14

The score would increase as we move from right to left until *e* had been taken in, at which stage it would in fact be $15^2/16$. The picture is best understood by reference to the associated attraction network (chart 15), from

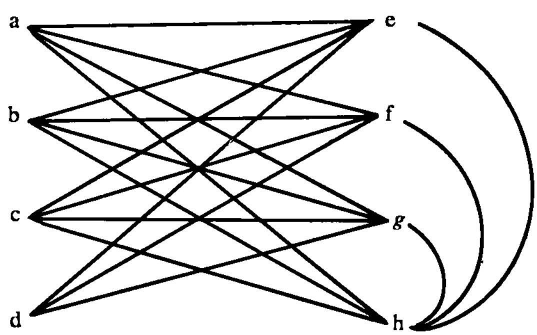

Chart 15

which it is clear that by shifting *h* back to the right, while actual cross-linkage remains at 15, the potential cross-linkage (y) is reduced to $5 \times 3 = 15$, giving a higher value to x^2/y (see chart 16). The practical analogue of this situation would be one in which we preferred to treat a phoneme as a consonant entering into unique consonant clusters rather than as a vowel

a	*b*	*c*	*d*	*h*	*e*	*f*	*g*
a				1	1	1	1
	b			1	1	1	1
		c		1	1	1	1
			d		1	1	1
				h	1	1	1
					e		
						f	

CHART 16

entering into unique vowel clusters (the Zulu nasals /m/ and /n/ of words such as *hamba* 'go' and *intombi* 'girl' are traditionally regarded as consonants, although the language in general eschews homogeneous clusters).

It may finally happen that while no single transference can alter the value of x^2/y, an exchange of elements can do this. The example provided looks like a try-it-on-your-friends puzzle, but presumably has analogues in subgraphs of the affinity networks of natural languages (see chart 17). If

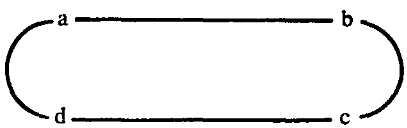

CHART 17

the vertices represent players and the links, pieces of string, the idea is for the players to divide into two groups in such a way that they are linked to one another by more than two strings.

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