The Features of the Roman Alphabet: A Tentative Study

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This paper is an attempt at decomposing Roman capital letters into their basic combinatory features. Different models of feature recognition are evaluated: a bidimensional matrix, a hierarchical tree and a quantal structure. The spatial as well as the seriality constraints are shown to be crucial. The adoption of a quantal perspective appears to be the most promising in the cognitive representation of letters. Assigning a definite space to each letter and isolating a discrete number of linear segments allows the unambiguous identification of any distinctive feature. A comparison between the analysis presented in terms of *quanta* and that proposed within the connectionist framework is shortly discussed.

1. Introduction

In this study we would like to present an analysis of Roman alphabetical letters in terms of binary distinctive features. Although this in not the first study on the topic (see for instance § 4), we will propose some new global pictures of Roman capital letters, showing how identification of the features has to be coupled to a parallel consideration of spatial dimension, crucial in writing as well as in visual perception.

The article is organized in two relatively independent sections. The first paragraphs (§§ 2 and 3) give a general introduction to the problems connected with graphemic analysis, with reference to classical studies and at the same time to some recent works on the topic of writing and reading. In the second, longer part of the paper, we try to decompose Roman letters according to their basic, combinatory features. Different proposals are tested, starting from the one proposed by Mounin (1970), more than thirty years ago, and finishing with the most appealing hypotheses elaborated in the field of recent cognitive or connectionist psychology.

In particular, we design three original models of recognition of distinctive features: the first one, in terms of a classical bidimensional matrix (§ 5); the second, in terms of a hierarchical tree (§ 6); the third one on the grounds of a set of linear and discrete segments located in a fixed region of the space (§ 7 and ff.). We will see that this last viewpoint is the best, since it is the only one able to embrace both the serial order of the features and the spatial constraint.

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2. *Graphemes and phonemes: a classical parallel*

The notion of grapheme is traditionally connected with that of phoneme. As is well-known, the graphemic analysis was introduced into linguistics in the late 1930s. [1] The letters and their relative norm of writing adopted by a speech community were studied as a system of distinctive units related to the units of the spoken language. The notion of the grapheme is strictly dependent on the Western tradition of writing. While it applied easily in the case of alphabetical scripts, such as Greek or Roman, it is of almost no use where other kinds of writing, such as syllabic and logographic scripts are concern-ed. For instance, in traditional Chinese grammar, the minimal unit of writing is the brush stroke: roughly sixty features allow all the characters to be drawn.

A comparison of graphemes and phonemes may be of interest for many reasons. A basic correspondence between graphemes and phonemes is obviously justified by their being semiotic units. Writing and speech are in turn semiotically related to one another. [2] The grapheme may be defined as the basic unit of (alphabetical) writing, just as the phoneme is thought of as the basic unit of speech. Aside from the definition, graphemes and phonemes have many other properties in common. First, both graphemes and phonemes are formal elements, in that it is possible to identify a closed set of forms defined only in terms of their reciprocal function, without any reference to the physical material they are made of. In the Roman alphabet, a <T> is always a <T> even if the vertical or orizontal line has a different slant, because of the individual hand writing. Within a specific range, the differently slanted letters do not correspond to different units of writing. Exactly the same is true of the different pronunciations of the /t/ phoneme produced in different contexts or by different speakers. Second, like phonemes, graphemes are arbitrary units, that is they are not naturally determined. In other words, there is no reason why the Romans should have used the signs they did for indicating the segments in their language. Even if they hadn't used vertical or sloping lines, but only circles, the semiotic code would still operate. Consider what happens today in electrically illuminated digits and letters: the signs are still those inherited from Roman, but they have been modified so as to avoid confusion between one sign and another, thus ensuring that the system functions without too much ambiguity (cf. Holenstein 1983). Third, in Saussurean terms, both graphemes and phonemes belong to the axis of the *signifiant* and are thus ordered in a linear fashion. For this reason, they are discrete elements,

i.e. there is a limited and finite number of them. The discreteness of the basic units is more evident in writing, especially if capital or typed letters are used, than in speech.

The linear order of the units accounts for the digital character of their perception. As a general principle, meaning has to be recognized as the crucial factor in the processing of spoken as well as of written units, whatever the perceptual strategies followed by the listener/reader (cf. Coulmas & Ehlich 1983: *passim*; Garman 1990: *passim*). However, both in speech and writing (or better, reading), digital perception coexists with holistic perception, based on cognitive *Gestalten*.

The medium used for expressing language – acoustic-auditory for speech, visual for writing – could interfere with the mode in which the message is transmitted, by also modifying the degree of its discreteness. Ludvig (1983: 39) claimed that "due to the transitory character of the acoustic medium, spoken language is organized by continuity, connectivity and integration – to mention just the supra-segmental features in addition to intonation. By contrast, because of the visual medium, written language is organized by discreteness, separability and segmentation".

In my own view, the difference is not so clear. To begin with, production should be kept distinct from perception. In the production of speech, sounds are coarticulated and interconnected, so that the phonetic output is really a *continuum*. In writing, at least when using capital letters or typing (because the situation is partly different in cursive writing) the letters of the alphabet are discrete elements and clearly separated. In perception, the situation could be reversed: sounds and the phonemes they represent are perceived in a linear manner by the ear and the cognitive process could have its basic guide in the segments of the phonetic sequence. In reading, the perception of letters as well as of words is not only linearly governed, but it works in a holistic manner too. The difference is strictly dependent on the perception organs: the ear perceives linearly, although with constant reference to the mental lexicon, while the eye follows holistic paths of perception from the very early stages of the decoding process.

As is well known, the problems connected with speech perception are far from solved. The experimental studies carried out on this topic have provided evidence in favour of several different units: acoustic features, articulatory gestures, phonemes, context-sensitive allophones, syllables. Up to now, the results suggest the relevance of more than one basic unit. Therefore, "no definitive answer to the unit of perception question is available" (McQueen & Cutler 1997: 568). The picture is not clearer in the understanding of reading: the units of perception may be considered discrete or continous according to the different scholars. [3] However, to deal with such a complex topic is not our mind. We prefer to come back to the relation between units of speech and units of writing, within a semiotic framework.

3. The relative independence of letters

Both graphemes and phonemes are normally regarded as units of second articulation. [4] As such, they have no meaning in themselves, their value being only negative and relative. However, a different and more meaningful semiotic status might be assigned to the letters, by taking into account their special use in chemical symbols, as well as in acronyms. According to some scholars (e.g. Rosiello 1966; Holenstein 1983), graphemes should not be considered as units of second articulation. In Hjelmslev's terms, this would mean that graphemes were plerematic, and not kenematic signs, as phonemes are. The meaning of the grapheme would be the phoneme, and a grapheme would become a metasign, i.e. a sign of a sign, and its value would be not only discriminative (like that of the phoneme), but also determinative (like that of a morpheme or a word).

Such a view clearly derives from implicit assumptions regarding the priority of speech over writing. There cannot be any doubt about the asymmetric relation between the two codes: philogenesis and ontogenesis clearly show that spoken language is more natural and primitive than written language is, a clear throwback to this relation is given by spelling practice. But alphabetical writing does not only have the function of representing the phonemes of the spoken language. It also has an intra-systemic function, that of keeping the graphemes distinct from one another in order to avoid coalescence. As in the case of phonemes, a minimal distance between the units of the semiotic system has to be ensured; otherwise, the goal of transmitting information would not be reached. Although the alphabetic writing represents speech visually, once it has been established as a system, the value of each individual element basically lies within the system, and not outside of it. The value of <A> in Roman alphabet is given by the function this graphic element plays in relation to other letters in this alphabetical system. Since writing and speech are two distinct semiotic systems, the units of one semiotic code should not be viewed as dependent on those of the other one, because they have a

value of their own, inside the system they belong to. Therefore, as Teodorsson (1974: 27) claims, "graphemic systems have to be considered as autonomous and not mere representations of corresponding phonemic systems". [5]

As is well-known, the traditional view that writing is only a mirror of language, and an imperfect mirror at that, is very old, going back to Aristotle and Plato. In modern times, Saussure has asserted the secondary and instrumental nature of writing with respect to language: "Language and writing are two different systems of signs; the latter only exists for the purpose of representing language" (cf. Saussure 1916 = 1967: 28). [6] Many other scholars have confirmed the opinion expressed by Saussure (see Ludvig 1983 for a short review), and the study of graphemes has often involved the search for a correspondence with phonological units. Convinced that writing is only a way of representing language visually, scholars have often forgotten that writing is also a system self-subsistent, i.e. it is a structure made up of signs which have a value inasmuch as they belong to the system.

However strict the relation between letters and sounds may be, it cannot be defined in terms of a biunivocal correspondence. No historical alphabet illustrates the principle 'each letter stands for only one sound', for the simple reason that no historical alphabet may be a phonetic alphabet, like the *I.P.A.* The relation between phonemes and graphemes cannot be considered biunivocal either. In any writing system, there are numerous instances where such a correspondence is lacking. The typology basically covers the opposition between hypodifferentiation or hyperdifferentiation. In graphic hypodifferentiation, a grapheme stands for more than one phoneme or segment; e.g. Lat. <V> = /u/ and /w/, Ital. or English <s> = /s/ and /z/. In graphic hyperdifferentiation, a phoneme is represented by two different graphemes; e.g. Roman, /k^w/ = <QV>; English /f/ = <ph>. Sometimes, we have aphonemic characters too, where graphemes are 'bare', meaning they have no phonetic counterpart; e.g. <h> in Italian is a purely graphic element, with a diacritic function (e.g. *chiave* /'kjave/ "key") or, at the most, morphophonological status. [7]

In all forms of writing, there is a degree of redundancy as well as ambiguity. For instance, in Classical Latin three letters represent the same phonic element (<C K Q>); on the other hand, long vowels are not distinct from short ones in writing, although they represent different phonemes.

The hypothesis that graphemes are strictly dependent on phonemes is not supported by the data. The structural anisomorphism of speech and alphabetical writing is dual. On the one hand, there is no one-to-one correspondence between letters and phonemes; on the other, the internal structure of letters does not accord with that of phonemes. As we have already considered some instances illustrating the first aspect, let us now turn our attention to the second.

Consider for instance the Roman letters representing the class of vowels: in four, only lines are used, while a circle is formed in <O>. There is no one graphemic feature common to all the vowels. If we now pass to the class of stops, the picture is not very different: a vertical line occurs in some of the letters, but not in all, since the curve is the dominant feature in <C G Q>. Even a distinctive feature like [voice] has no suitable and systematic representation in writing. While in <B> and < G>, for example, the addition of a single element (a semicircle open to the left in the former case and a short line at the low right side in the latter one) does relate positively to <P> and <C>, as [+voiced] to [–voiced], in <D> *versus* <T> this direct, i.e. unmediated, correlation is lacking.

The reasons for this structural anisomorphism are obviously historical. Alphabetical systems normally have mixed origins: they were not invented *ex nihilo*, but are the result of successive adaptations of preexisting signs, formerly used to represent other languages. This is the picture which can be drawn for the Roman alphabet, "a mixture of Etruscan and Greek, the graphemic counterpart of a *Mischsprache* if you will" (Devine 1971: 352). If we could return to the moment when the first alphabet of all was created, we might perhaps discover the logic underlying it. However, even at this mythic time of origin, there is no reason to suppose a natural correlation, or a perfect correspondence, between writing and speech. From the historical point of view – the only one of any scientific value – there is no doubt that the shape of the letters does not conform to any logical criterion aimed at reproducing the phonological classes of the language.

4. Decomposition of letters

Since graphemes, like phonemes, are units of second articulation, they should be composed of minimal elements, a sort of structural atoms. For instance, in the letters <T> and <P>, we recognize a common feature (a vertical line) as well as features peculiar to each letter, a horizontal line over the vertical one in <T>, a semicircle open to the left and joining the upper right side of the vertical line in <P>.

This is tantamount to saying that the phonemes /t/ and /p/ share the features [-continuous] and [-voiced], whereas their place of articulation is different.

In alphabetical writing, it is always possible to identify a finite number of distinctive subgraphemic elements which allow the composition of every letter. If we examine the Roman alphabet, it is easy to see that each letter results from the combination of a few basic elements, which vary in shape, degree of slant and position.

Mounin (1970: 138 ff.) has already proposed an inventory of minimal features occurring in the Roman lower-case letters, although he does not speak of features, but only of 'formes graphiques minimales'. The number of basic elements recognized by Mounin is twelve (see Fig. 1). Among those, the entire vertical line and the circle are the signs most frequently used (ten and nine letters, respectively); then, the half-line (six letters) and the diagonal lines, one left-to-right and the other, right-to-left (both used for writing the same four letters).

However, the picture given in Figure 1 is unable to represent the lower-case letters of the Roman alphabet in an unambiguous fashion. As Mounin himself (1970: 141) observes, <b> cannot be kept distinct from <d>, nor <p> from <q>; neither <p> from <b> neither <d> from <q>: these four letters have in common the same basic elements (the vertical line and the circle), without any other differentiating feature. Two new features are therefore added by Mounin, the one relative to the position of the line (over or under the base-line of writing) and the other relative to the order (the line before or after the circle).

In our opinion, the position of the line is the only feature which is needed, if position is defined with reference to a definite space for any letter of the alphabet (cf. *ultra*, the notion of 'grid'; see §§ 7 and ff.). The letters for nasals are not even differentiated; a feature relative to the number of 'shanks' (one for <n>, two for <m>) is needed. The diagonal lines involved in the writing of <v w x> cannot differentiate between these three letters. Even here, a feature of position becomes essential: the justaposition (in <v> and <w>) contrasts with the overlapping (in <x>) of the diagonals. Furthermore, the number of lines is important (two diagonal bars in <v>, but four in <w>).

The size of the 'atoms' involved in the letters is relevant, too: in <k> the diagonal lines are roughly half as long as those occurring in <x>. In the same way, the horizontal line is not the same size in <e f t z>, although this is the common atom assigned to these letters.

Signes	Apparaissant dans	Nombre de lettres
|	b d f h j k i p q t	10
o	a b c d e g o p q	9
ı	a ı m n r u	6
\	k v w x y	5
/	k v w x z	5
?	h m n u	4
—	e f t z	4
⌢	f j r	3
·	i j	2
ʾ	g	1
s	s	1
/	y	1

Fig. 1. The analysis of the Roman letters as proposed by Mounin (1970: 138).

The search for weak points in the analysis presented in Figure 1 still continues. We prefer to limit our criticism to a few final comments. First, the character used for <g> by Mounin (1970) is rather odd. This oddity is reflected in the introduction of a special sign as a distinctive feature which is employed for this letter only. Second, there is a letter, i.e. <s>, which is not decomposed into its atoms, but stays as a whole. This letter should therefore be considered as being outside the system, since it does not have any feature in common with the other elements of the system. In our opinion, this is a very weak point of the analysis. In a semiotic structure, each element belonging to it has to share certain properties and, at the same time, has to have properties in contrast with the other elements of the system. Since there is no doubt that <s> is a letter of the Roman alphabet, in principle its analysis must not be completely different from that of the other letters.

Finally, if we include the position and the size of the minimal elements in the decomposition of lower-case letters as proposed in Fig. 1, we can easily reach a total of more than twenty basic signs accounting for twenty-six letters. Mounin (1970: 143) concluded his analysis by denying the occurrence of a double articulation in the alphabetical system. While in speech the distinctive features are less than the phonemes they form, thus ensuring a high level of economy to the phonological system, in writing there seems to be no real economy, at least in the analysis we have considered so far.

As in the previous sections of the article, even with respect to

the atoms composing the units of the two semiotic systems (speech and writing), it seems that a structural anisomorphism has to be recognized. Before assuming such a negative point of view, we would like to make another attempt. We will try to decompose the letters of the Roman alphabet into their minimal elements following the principle of economy as far as we can. In agreement with the phonological analysis, we will call these elements 'distinctive features'.

5. A matrix of distinctive features

Our attention will be devoted essentially to capital letters of the Roman alphabet as it is currently used in the Western world (i.e. twenty-six units). The task of finding the distinctive features seems easier in the case of capitals with respect to lower-case letters. In our decomposition of the Roman letters, the primary feature will be the line, and the second, the arc. These two features may be combined and vary in position, size and slant (the last parameter, in the case of the line only). The shape of some letters has changed over time. However, in the following analysis of the distinctive features of Latin graphemes, we will consider the letters in their traditional form, the basis of the entire Western tradition down to modern type-written characters.

Lines only occur in the following letters: <A E F H I J K L M N T U V W X Y Z>, curves only in <C S O>, the last letter consisting of a closed curve, more precisely a circle. In <B D G P Q R>, a combination of lines and arcs is found. Lines are more frequent than curves. All vowels except <O> employ lines only. Three plosives are formed by combining a line with one or two arcs (<B D P>). Moreover, lines may slope with respect to the plane of writing. If they do not, they may be either vertical or horizontal.

Some of the letters are specular, i.e. they do not change form if written from right to left. These are < A I O T U V W X Y>. The other letters, being asymmetric in form, show the direction followed in writing, from left to right. These asymmetric letters are formed by joining one or more elements to the right-hand side of a vertical line. The elements added to the vertical bar may be linear or curvilinear. If linear, they can slope or not, and if a sloping line, this has to be followed by a vertical line (e.g. the nasals <M N>). Lines and arcs may be added to the upper (<P F M>) or lower right-hand extremity of the vertical line (<G L Q>), or to both (<B D E K N R>) or to again its middle (<E F>).

From this short analysis it may already be seen that the vertical line is the least marked feature, in that it occurs in the majority of letters (= fourteen out of twentysix). The same is true of lower-case letters, [8] as well as of cursive writing. With reference to a classical notion of phonological analysis, the maximal functional load will be assigned to the vertical line. Let us now try to represent the distinctive features we have identified so far in a sort of matrix, where binary oppositions are placed alongside contrasts based on more than two choices; see Figure 2.

	|			—			\			/			(			)		
	l	*m*	*r*	*t*	*m*	*b*	*u*	*d*	*th*	*u*	*d*	*th*	*u*	*d*	*th*	*u*	*d*	*th*
A					+				+			+						
B	+															+	+	
C															+			
D	+																	+
E	+			+	+	+												
F	+			+	+													
G			+		+										+			
H	+		+		+													
I		+																
J		+						+										
K	+							+		+								
L	+					+												
M	+		+				+			+								
N	+		+						+									
O															+			+
P	+															+		
Q								+							+			+
R	+							+								+		
S													+			+		
T		+		+														
U	+		+			+												
V									+			+						
X									+			+						
Y		+					+			+								
W								+	+		+	+						
Z				+		+						+						

Fig. 2. Matrix of the distinctive features of Roman capital letters.
Legenda: | = vertical line; — = horizontal line; \ = sloping line right-to-left; / = sloping line left-to-right; (= arc open to the right;) = arc open to the left; l = left; m = middle; r = right; t = top; b = bottom; u = up; d= down; th = throughout.

The fundamental principle followed in creating the following matrix has been the identification of the lowest number possible of discrete variables. The variables may be combined with each other. Only the essential elements are included in the matrix. Each terminal feature is conceived of as discrete and binary. This means that a feature has to be marked with a plus or a minus sign.

This matrix is redundancy-free, since it does not contain full values for all the features employed. Positive values only are given, and blanks in the matrix mean negative values, as it happens for segments in *Underspecification Theory*.

From the account given so far, Latin graphemes appear to show different degrees of markedness, measured by considering the number of features necessary in order to identify the grapheme. <C I> are the least marked, since their matrices comprise a single positive feature only. The shapes of these two letters are very different, but in each case the unmarkedness in terms of features indicates that they are written with one continous hand movement. The most marked letter are <E M W>, which require four different features for their discrimination. Most part of the letters require two or three features.

6. Seriality problems

As all matrices, our matrix is static, that is it does not imply a temporal organization of the features. From such a representation, we do not know which feature has to be written before the others. At the same time, we do not know the common position of the features in the space occupied by the letter. The question has therefore two symmetric facets: the temporal sequence on the one hand and the spatial filling on the other. Once again, categories of time and space co-occur and are mutually constrained.

For instance, in the case of <P> we have to know whether the arc open to the left has to be written before or after the vertical line. The information is actually obtainable in this case from the indication of the left vertical line: writing from left to right, if the vertical line occupies the left position, the arc may receive the following position only.

A general criterion might be the priority, both spatial and temporal, of the vertical line in all letters showing this feature. The constraint correctly predicts letters like <B>, <L>, <P>, <R> and many others. In the case of <T>, the letter should be written as <Γ>; otherwise, we need the indication relative to the middle position of the vertical line. The same goes for <H M N>, which would become <| |–>, <| | \/> <| | \>, respectively, without the information concerning the position of both the vertical bars. Undesirable results might be obviated by the introduction of a 'continuity constraint': if in a letter there are more than one feature, each feature has to be connected with at least one other.

Certain problems arise from the lack of ordering in letters with sloping lines: in <V> the first line is sloping left-to-right, while in <A>, it is slanting right-to-left. Without any indication on the linear axis (first position for \ in <V>, but second in <A>), these two letters might be upside down. Information about line crossing is needed too, in order to correctly predict <X>; otherwise, that is on the simple ground of the features occurring in the matrix, <X> and <V> cannot be kept different. Furthermore, linear ordering is again crucial in <W>, since the 'continuity constraint' alone cannot provide the right shape of the letter; </\ ∧> might be possible too.

A major problem concerns <O>: from the matrix we do not know which of the two arcs has to occupy the left position and which is on the right. Therefore, <O> might become <)(>, with a possible contact point in the middle. The same goes for <Q>. There is no problem for <S>: the matrix gives us the information concerning the position occupied by the two different arcs on the vertical axis, while there is no indication about the horizontal axis. However, even if the two features were written one after the other, we could still recognize the intended character.

In order to take into account the seriality problem, we may try to represent the features of the alphabetical letters in the shape of a tree, thus introducing a hierarchical criterion. Using the feature geometry which has been proposed for phonological representation, we might therefore think of each character as an alphabetical root, where different features can be activated in a special order. A tentative tree is shown in Figure 3.

A tree like this can represent the internal hierarchy in the organization of features as well as the dependency relations existing between the different features. The hierarchical structure accounts for the implicational relations between features. Some features may be predicted on the grounds of others. For instance, [–line] indicates a negative value for all the features dominated by that node in the graphemic tree. Similarly, [+arc] calls for the specification of its position in the writing space.

However, as in the previous matrix, given the tree for a letter, we do not know the common position the terminal features occupy in the space. Whatever the representation (matrix or tree), its discrete nature is its basic characteristic. But the problems connected with feature ordering are still not solved. Although the tree is less static than the matrix, it does not give us all the information needed in order to identify the different characters unambiguously.

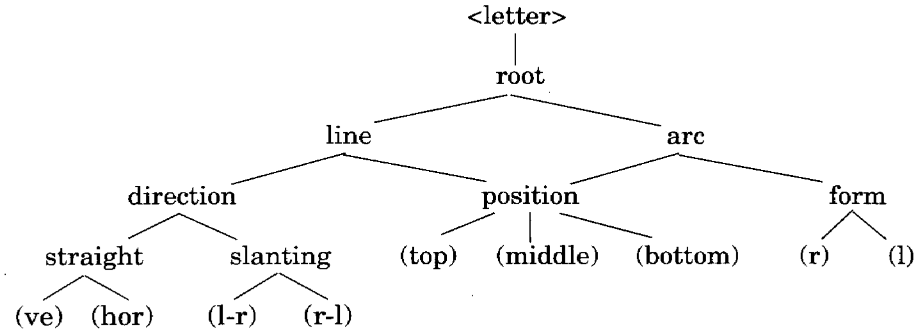

Fig. 3. A tentative hierarchical tree for Roman letters.
Legenda: ve = vertical; hor = horizontal; r-l = right-to-left; l-r = left-to-right; r = arc open to right; l = arc open to left.

7. *The quantal nature of alphabetical letters*

Special attention has therefore to be devoted to seriality: the alphabetical letters cannot be represented without reference to the ordering of the distinctive features. This is an important difference between phonemes and graphemes: in phonemes, the features are normally simultaneous, while in graphemes the linear order appears to be fundamental for capturing the essential nature of letters. It is true that in the case of certain complex phonetic segments the same feature can be marked in a different way with respect to the temporal order. For example, in an affricate like [ts], the feature [continuous] is first marked 'minus' and then 'plus'. But in general the features occurring in a phoneme are not ordered linearly: for instance, in a /p/, [-voiced] and [-cont] are simultaneous; the same happens in /i/ for [+high], [+ant], [-round], and so on. On the other hand, in graphemes, the order of the features appears to be fixed. For instance, in writing a <B> or a <D>, it seems obligatory to begin with the vertical line.

However, more than feature ordering, what is crucial is the position which a single distinctive feature occupies in the space of the letter. From this point of view, a promising idea might be to assign a defined space to each letter and then to divide this space into a fixed number of other smaller spaces. In our matrix, a division of the space through three lines is already present on the vertical axis (three different positions: top, middle and bottom), as well as on the horizontal one (left, middle and right). A further step might be to conceive this defined space as a grid with a fixed number of points.

The same criterion has been followed by Hofstadter & Mc Graw (1995: 420 ff. = 1996: 450 ff.) in their proposal concerning the ambitious project called *Letter Spirit*. This interesting project aims to prepare computer software capable of inventing new styles of writing on the grounds of a few seed letters. In *Letter Spirit,* each lowercase letter of the Roman alphabet is given by a set of discrete variables. These variables are segments. Lines only are admitted in the gridletter (cf. *ultra*), in order to avoid all the complexities involved in curves.

Hofstadter & Mc Graw (henceforth H&McG) believe letters are rich, full-fledged concepts (H&McG 1995: 412 = 1996: 441). The internal structure of these cognitive categories consists of what they call 'roles', that is explicit cognitive forms. Roles can be of two kinds: simple roles and relation roles (r-roles). Roles are simple forms in a defined space, while r-roles are more abstract structures connecting primary roles to each other in the representation of a letter. Each letter consists of a complex of roles and r-roles. The relevance of roles – both primary and relational – is variable, depending on the degree to which its presence or absence matters. Roles, just like *wholes*, i.e. complete letters, are "concepts in their own right, with somewhat nebulous boundaries" (H&McG 1995: 415). The reduction of a whole letter into a finite set of roles implies an important decrease in complexity in the analysis, with a parallel increase in simplicity and naturalness. The notion of role is rather similar, although not identical, to that of a distinctive feature we are accustomed to.

More original is the introduction of the gridletter. In their *Letter Spirit* project, H&MG do indeed make a crucial reference to a fixed grid defined by twenty-one points arranged in a three by seven array. This rectangular grid defines the space for each letter. Four horizontal lines (the top line, height line, baseline and bottom line) divide the fixed space into three sections: ascender zone, central zone and descender zone. Each section has the same size, defined by three points, both in the horizontal as well as in the vertical axis. The grid constrains the alphabet, which has to be adapted to the fixed layout. As a consequence, the product of the analysis will be not simply an alphabet, but rather a *gridfont*. In Figure 4, the grid proposed by H&McG (1995: 421) is presented.

The variables forming the letters are segments connecting two contiguous points in different directions: horizontal, vertical or diagonal. These segments, all with a discrete nature and fixed size, are called *quanti*. Given the grid of twenty-one points, the potential *quanti* are sixty-six. They might correspond to our distinctive features, with this difference that only straight lines have quantal nature in *Letter Spirit*. [9] All the *quanti* are virtually available for the definition of any letter. The selection of certain *quanti* rather than others depends on the shape of the letter. The *quanti* obey a binary constraint: they may be only turned on or off.

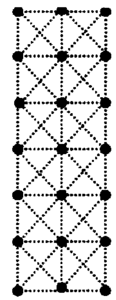

Fig. 4. The grid for *Letter Spirit*. The *quanti* are the segments connecting couples of points; from Hofstadter & Mc Graw (1995 = 1996: 451).

For lower-case letters, three sections are necessary. The middle section (i.e. between the height line and the baseline) is always filled, while the top as well as the bottom sections may be empty (e.g. <a c e>) as well as full (e.g. <b g f h k>); see Figure 5. Gridletters are restricted to shapes that can be made out of short line segments on the fixed spatial grid.

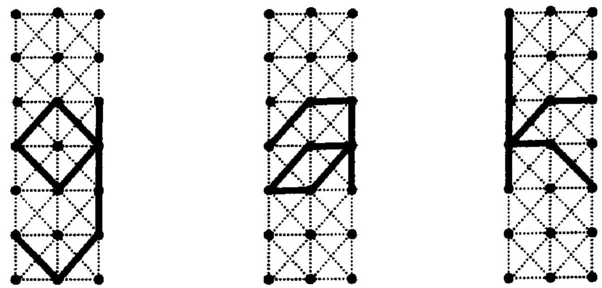

Fig. 5. Three examples of grid letters, formed with different *quanti,* from Hofstadter & Mc Graw (1995 = 1996: 451).

8. *A grid for capitals*

If we follow the suggestions of H&McG (1995) for the representation of Roman capitals, first of all we have to define the grid, i.e. the space which may be occupied by the *quanti* forming the letters. The grid will still be rectangular, with the same width, but a different height, since in the case of capitals, two top-down sections are enough. Therefore, two basic horizontal lines will be drawn: the top line and the bottom line. Another line is needed, which may be considered to be the central line; in the case of capital letters, there is neither a height line nor a baseline. Furthermore, a special constraint exists: capitals must all have the same height. The vertical axis will be wholly filled, although this does not imply filling by straight lines alone.

In Figure 6 we present our grid of fifteen points forming a rectangle and defining the space for each letter. The potential *quanti*, i.e. the segments connecting two contiguous points, having a discrete nature and fixed size, are thirty-eight. Their number is then lower with respect to the original proposal by H&McG (1995; sixty-six *quanti*), given the greater difficulties of dealing with lower-case letters.

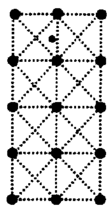

Fig. 6. The grid for the Roman capital letters.

In Figure 7, a tentative overall picture of grid capital letters of the Roman alphabet is presented. First of all, we observe that not all the letters have the same simplicity, simplicity being defined as the number of *quanti* turned on in the representation of the letter. Second, some of the letters are the product of the combination of a simpler letter with the addition of other specific *quanti*. For instance, <J> and >T> may be derived from <I> plus a special *quantum*; the same goes for <R> and <P>. Similarly, <C> is included in <G>, as well as in <O> and <Q>. Furthermore, though a vertical line occurs in many letters, in particular in <E, F, H, K, L, M, N>, <I> cannot be considered as seed letters, since the vertical *quanti* do not occupy the same space in the grid of <I> and in that of the other letters.

Not all the letters have the same aesthetic value. The recognition of the pattern is different too. By using only the linear *quanti*, the first four letters of the alphabet are, for instance, drawn in a rather unnatural fashion. While many letters are clearly recognisable (e.g. <E G H I K> etc.), there are some characters which appear rather odd (e.g. <Q V W X Y Z>). In particular, <W> is hardly recognisable, since the grid space on the horizontal axis does not seem to be enough for this letter. On the other hand, in drawing <X> and <Z>, the 'contiguity constraint' shows all its importance: if *quanti* could connect points that are not even contiguous, the shape of these letters would be improved.

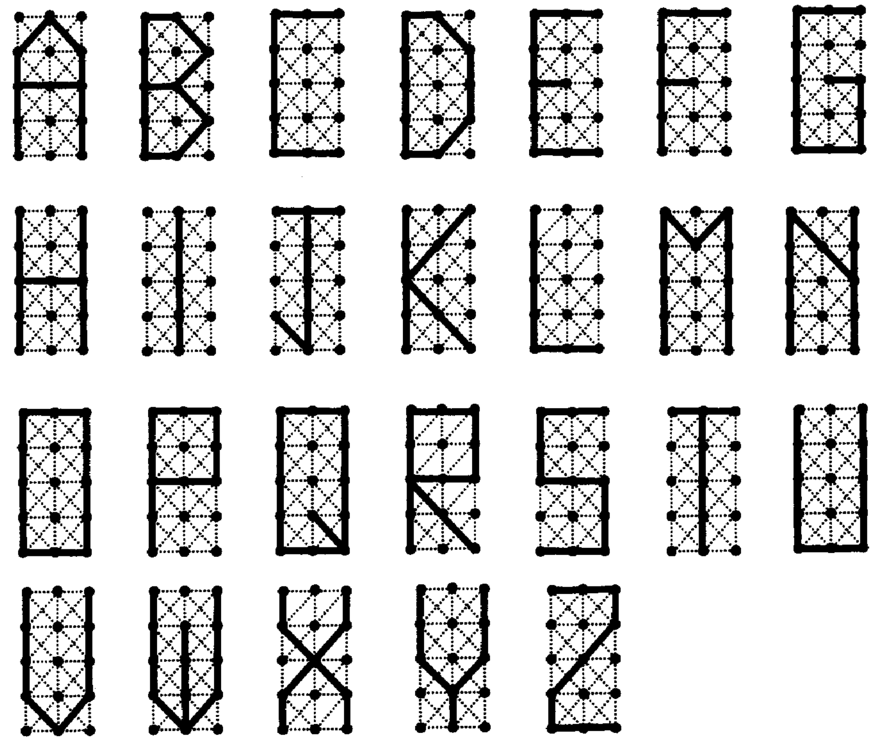

Fig. 7. Grid capital letters for the Roman alphabet.

If we wish to represent all the capital letters in the shapes we are used to in reading and writing, the constraints on the original *Letter Spirit* should be relaxed. In particular, we might assume what follows: a) the grid has the shape of a square, instead of a rectangle;

b) the *quanti* would not be only segments, but also curves; c) both segments and curves may connect two points that are not contiguous.

The square space for each letter is now a fixed grid of twenty-five points, which define sixteen small squares; see Fig. 8. The potential linear *quanti* will be seventy two (twenty horizontal, twenty vertical, thirty-two diagonal), without counting those connecting two points that are not contiguous.

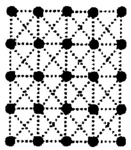

Fig. 8. The square grid for the capital letters.

In Figure 9, three new grid letters are presented (<A B D>). They show the switching on of certain *quanti*. The reader may try to draw the other characters of the alphabet. The arcs employed might be fourteen; six of them will connect two not contiguous points of the grid (<C G D O Q>). Ten linear segments connecting two not contiguous points are used, too (<A D G J>). The aesthetic aspect of the letters can become better than before in some cases, but the economy of the representation is much lower than in the preceding proposal, where the *Letter Spirit* constraints were taken for granted. Moreover, the improvement in the aesthetic perception might be of minimal relevance from the cognitive point of view. As H&McG (1995: 420) suggest, these surface aspects of letterforms may be forbidden if we want to concentrate on deeper and conceptual levels of the processing.

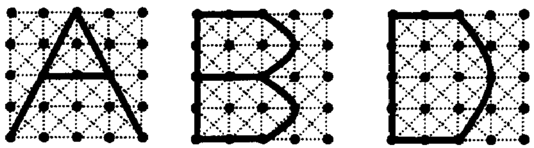

Fig. 9. Three letters with the square grid.

In their analysis of the Roman alphabet, H&McG (1995: 452 = 1996: 483) propose to distinguish between 'parent' letters (i.e. fully-finished letters) and 'child' letters (i.e. still evolving letters). They show how the form of a 'child' letter may sometimes influence and

change the spirit, i.e. the style, of a 'parent' letter, too. This means that every letter is always potentially subject to revision, under the influence of the construction *in fieri* of the other letters.

8. The connectionist approach

An alternative design for the analysis presented so far in terms of *quanti* for letters may be found within the connectionist framework. Alphabetical letters have aroused the interest of many psychologists during recent decades. The idea of decomposing Roman letters into a set of distinctive linear features that are spatially constrained was already present in the seminal work by Rumelhart & Siple (1974), based on pattern recognition. The grid showing the basic fourteen line segments required to construct the whole Roman alphabet in capital letters is reproduced in Figure 10. Examples of grid letters are given, too.

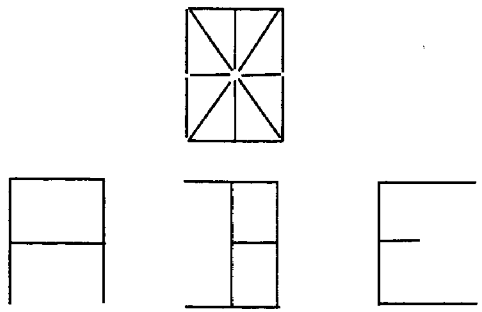

Fig. 10. Reference grid and a few examples of grid letters from Rumelhart & Siple (1974).

As in the grid proposed by H&McG (1995), there is a finite space where each linear feature is located. Each letter is assigned the same space. Each linear feature is defined by the length, slant and location in that fixed space. Not all the features have the same length. In particular, diagonal lines are longer than horizontal and vertical lines, if inside the grid; top and bottom horizontal lines are longer than any other line; vertical external lines are broken, while the horizontal external ones, are not. The different treatment of the external lines (two features if vertical, but only one if horizontal) allows the system to save the global number of features, thus ensuring more economy, which is important within a computational model. In Rumelhart & Siple (1974: 99), each straight-line segment "acts as a functional feature with respect to some alternative set of stimuli". This geometry of the characters provides an interesting simulation of a 'guessing model' able to account for letter and word recognition.

McClelland & Rumelhart (1981) and Rumelhart & McClelland (1982) have devised a more complex model for the recognition of letters and words, where context effects, and in particular lexical constraints, are also taken into account. In this model, visual perception results from the interaction between different levels of processing: a feature level, a letter level and a word level. The authors assume that visual perception is spatially parallel, that is, visual processing of a region in space occurs at several levels at the same time. As far as features are concerned, in this model too, features are conceived as binary. Each feature may receive excitatory or inhibitory activation on the grounds of the feedback with the higher level of processing (basically, the lexicon) as well as of the constant parallel comparison of the occurring letter with the intended one.

We do not need to discuss here the complex connectionist architecture built up by the two scholars. From our point of view, what is relevant is the recognition of a set of linear segments and the crucial reference to a fixed region of the space as distinctive features in the processing of alphabetical letters.

While the work by McClelland & Rumelhart (1981) and Rumelhart & McClelland (1982) was basically perception-oriented, the studies by Grebert *et alii* (1992) can be said to be production-oriented, and are, therefore, more similar to the *Letter Spirit* project. The connectionist model designed by Grebert *et alii* is called *GridFont*. It is a feedforward network developed on three different layers of a variable number of nodes. This network is assumed to learn by backpropagation. After training on five full gridfonts, the network were presented some letters of *Hunt Four.* The task was the production of the whole alphabet. The results obtained by the *GridFont* project in designing the remaining twelve letters were not satisfactory and rather unreliable, since many of the shapes produced by the network were fairly remote from the intended categories. The five fonts given as the input to the network, although very useful, were chosen with care in order to obtain the best result. However, they became misleading, because the network was working on stereotyped information, without a constant feedback from the context as well as from the work already done by the system itself. [10]

In particular, in *GridFont* the letters are created one at time, but

the shape of a letter produced has no direct effect on the creation of any others. The basic point of reference is the set of letters given as the input to the network. As H&McG (1995: 466) ironically observe, cognition is not "a free lunch, courtesy of distributed representations"; therefore, cognitive science "must pay far more explicit attention to the level of concepts and analogies, and move away from the magical hope that such phenomena (...) will simply emerge somehow all by themselves, as a result of training networks of artificial neurons" (H&McG 1995: *ibidem*).

The distributed representations typical of connectionist systems are not so dynamic and interactive as the mind is. A human designer could extrapolate the style (i.e. the 'spirit', in H&McG's terms) of a new font, presented in a few characters alone, by a continuous processing of all the information available from the input as well as from any letter just created. In other words, one single step in the design can trigger a series of further steps. Sometimes the whole system of characters has to be reconsidered in the light of the last letter designed. Instability and unpredictability are typical of the act of creation. Our tentative picture of Roman capital letters in terms of quantal features tries to satisfy these requirements.

9. Conclusion

We have considered here the basic units of the written code, i.e. the graphemes, in comparison with the units of the spoken code, i.e. the phonemes. Despite many common properties, graphemes are shown to be different from phonemes, basically as far as the production and the perception of these two units are concerned. Given the structural anisomorphism between speech and alphabetical writing, graphemes are shown to be signs that are partly independent on phonemes.

The relative autonomy of graphemes allows us to analyze their distinctive features. Roman capital letters have been decomposed into their 'structural atoms' by introducing marks comparable with those traditionally employed in phonological analysis. Both the matrix and the hierarchical tree have shown the relevance of the spatio-temporal organization of the distinctive features.

Since ordering and spatial position of features are crucial in the representation of letters, a quantal perspective, based essentially on the recognition of minimal, discrete and spatially defined segments, appears to be suitable in graphemic analysis. Our proposal might be considered as a preliminary step in such a direction. Future studies will no doubt show the appropriateness as well as the limits of the outline contained in the present paper.

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Notes

[1] The literature on the topic is quite wide; however, the fundamental studies can be considered those by Stetson (1937), Uldall (1944), Pulgram (1951; 1965), Hjelmslev (1954), Vachek (1966), Lüdtke (1969).

[2] On the complex relation between speech and writing, we refer the reader to the interesting volume edited by Coulmas and Ehlich (1983), as well as to the broaden and exhaustive studies by Coulmas (1985) and Vachek (1989).

[3] An introduction to the problems of perception is presented in McQueen & Cutler (1997); see also Garman (1990) and Gernsbacher (1994: *passim*).

[4] For a different opinion, see Mounin (1970: 142-143).

[5] Arguing in favour of the autonomy of graphemic units in relation to the phonemic ones, Teodorsson (1974: 26) reaches a new, controversial definition of a 'dead language' as a language not manifested in any functioning linguistic system. In these terms, neither Latin nor Ancient Greek are dead languages, since their graphemic systems are both operative and efficient.

[6] Saussure's view on writing is very complex. It may be summarised under two basic aspects, the one theoretical and the other one methodological. Theoretically, the crucial point is the relation between writing and language, i.e. *langue* (not speech = *parole*), while the methodological aspect is strictly related to the phonetic interpretation of the alphabet used in the documents of the ancient languages. On the topic, we refer the reader to the analysis by Vallini (1983).

[7] Cf. the contrast between *a* (preposition) and *ha* (verbal form), or *anno* (noun) and *hanno* (verbal form).

[8] Remember the analysis made by Mounin (1970); see *supra*.

[9] The attribute 'quantal' is here synonymous with discrete and defined numerically. No reference is made by H& MG to the well-known phonetic theory proposed by K. Stevens for speech production.

[10] See Hofstadter & McGraw (1995: 459-463 = 1996: 491-494) for further specific comments on the work by Grebert *et alii* (1992).

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