A featural analysis of the Modern Roman Alphabet

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The present article shows that the letters of the Modern Roman Alphabet have an internal structure that is highly systematic in both inner-graphematic and functional-phonological terms. The framework of analysis is Optimality Theory. This approach is congenial for the data at issue as many apparently unmotivated exceptions are optimal choices among competing candidates that are evaluated by violable ranked constraints. The results of the present investigation corroborate a branching correspondence model in which general modality-independent constraints such as dependency, compositionality, markedness and iconism are shown to have independent modality-specific instantiations in speech and writing with bidirectional correspondences serving as functional links across modalities.

1. Introduction

A widely accepted assumption in phonology is that the basic units of phonological representation are not segments but features. The role of features is twofold. First, they serve to distinguish sounds from each other (distinctive function); secondly, they establish sound classes and are the basic elements of phonological rules (classificatory, systematic function). Features have been successfully transferred to other linguistic domains such as semantics. This suggests that the organization of linguistic information in terms of features and the general principles of featural organization such as binarity or privativity and markedness are not restricted to the sound system.

Many researchers dealing with correspondences between letters and sounds assume that the letter is the smallest unit of analysis. Research dealing with letter components is found in other fields of research such as information theory and machine character recognition (e.g. Eden & Halle 1961,

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Coueignoux 1981, Govindan & Shivaprasad 1990), cognitive letter recognition and developmental studies (e.g. Gibson et al. 1963, Gibson 1969, Bouma 1971, Gibson & Levin 1975) or graphetics (e.g. Althaus 1980, Scharnhorst 1988). Systematic correspondences between letter and sound features as well as linguistic constraints on the featural organization of letters fall beyond the scope of these researchers. Nevertheless, some authors, among which William Watt and Herbert Brekle deserve special mention, have offered graphetic analyses which are a good starting point for a more systematic constraint-based approach.

The featural analysis of the present investigation pertains to the Modern Roman Alphabet (MRA). Whether or not some assumptions can be carried over to other alphabets is an open question for future research. The broader theoretical frame of analysis is Optimality Theory (OT). Its characteristic assumptions are that constraints are violable and ranked relative to each other.

The outline of the paper is the following. The next section discusses the general assumptions about the relationship between language, speech and writing defended in this paper (Section 2). Then, we proceed towards a characterization of the substance of written language in terms of perception and production as well as in relation to the substance of speech (Section 3). After a discussion of the method of letter segmentation (Section 4.1), we introduce the core inventory of MRA-characters as well as the most important features (Section 4.2), and finally, we delimit the system of MRA-letters from that of digits and punctuation marks by introducing graphematic constraints that are ranked differently in the various subsystems (Section 4.3). The insights gained by this intrinsic graphematic analysis will be used to characterize the main phonological functions of letter features (Section 5). The intrinsic graphematic and functional analyses enable us to systematize the relationship between the minuscule and majuscule variant of a letter (Section 6). Section 7 recapitulates the main results of the paper and mentions still open questions.

2. General assumptions: Language, speech and writing

Many, but not all empirical results to be presented in the following sections can be recast in various frameworks. But some of the most important results have been made possible and can be fully understood only on the basis of the general assumptions defended in this paper.

A standard view on the nature of writing systems is that they are artificial products that can be adopted or reformed at will, that they have to be learned deliberately and that they are secondary and derivative on spoken language, which is considered to be primary (cf. Daniels 1996 and the general introduction to this volume). Daniels' (1966: 2) conclusion is that the theory of writing must be very different from the theory of language and that patterns or principles that describe language are not expected to apply to writing. This view justifies derivational accounts on writing systems, Nunn (1998) and Sproat (2000) serving as more recent examples. In these accounts, written representations are derived from spoken language representations, phonological representations playing an important role. Constraints intrinsic to the graphematic level are treated as surface phenomena and dealt with marginally.

The view defended in this paper departs radically from the above-mentioned body of assumptions (cf. also the general introduction to this volume). In a paper dealing with the syllable in spoken, written and sign language (Primus 2003) a branching correspondence model was proposed that can be graphically illustrated as follows:

(1) modality-independent constraints of language

kinemic/visual[1] system		articulatory/auditive system		gestural/visual system
written language	⇔	spoken language	⇔	sign language[2]
	correspondences		correspondences	

The scheme is meant to emphasize the logical connection between general constraints and modality-specific subcases of such constraints. It is not a derivational model comprising autonomous modules with modality-independent constraints operating at a deep structure and modality-specific systems being derived surface phenomena.[3] Contrary to Daniels' assumption that patterns or principles of language are not expected to apply to writing, our model claims that written language, specifically the internal structure and function of letters, obeys modality-independent constraints (cf. also Primus (2003) for syllable-related phenomena). These constraints have different modality-specific manifestations as a consequence of the differences in the linguistic substance, i.e. the kinemic/visual and articulatory/auditive system.

The model is compatible with the view that the primary function of a writing system is to match (and mentally activate) spoken language representations.[4] But it also emphasizes the centrality of very general and reliable mapping rules from graphematic representations to phonological ones (cf. one of the earliest proposals in Venezky (1970)). This direction of fit will be highlighted in this paper in line with the general perspective of the present volume.

The view on the Modern Roman Alphabet defended in this paper is best summarized by Watt (1988: 199) as follows:

> The letters of the ordinary English alphabet, some of which date back to Egyptian forms of five millennia ago (…), belong to a coherent set of signifying elements that have mostly been shaped gradually through changes introduced inadvertently as part of their casual transmission from generation to generation. In short, they have been shaped, in large degree, by processes comparable to those which shape language itself; if for that reason alone, then, letters of the ordinary alphabet would seem to offer themselves as fit objects of semiotic curiosity. On the other hand, their manifest differences from the elements of natural language are striking as their similarities.

In line with the assumption that patterns or principles that describe language are expected to apply to writing and speech, a few general constraints will be formulated that are pertinent for the data under consideration. Some of them, such as the adjacency constraint on concatenated units, are so obvious that they will not be discussed further.

A more interesting constraint imposes an asymmetrical dependency structure on concatenated items, as stated in (2). Following OT-conventions, the name of the constraints appears in small capitals. Cf. (2):

(2) Dependency / Prominence: Among two concatenated sisters one is dependent on / more prominent than the other.

A reliable criterion for dependency is that the presence of one element (called the head or nucleus) is a necessary condition for the presence of the other element (called the dependent). The prominent role of the head is also manifest in the properties it shares with the mother node (cf. Hawkins' (1994) reconstruction of heads as mother-node-identifying elements and head-feature percolation in modern syntactic theories). A notion closely related to dependency is prominence. A well-known observation is that initial edges (syllable onsets, word-initial syllables) are more prominent than final ones and that the nucleus is more prominent than the other parts of the syllable. Such elements and heads share the property of contributing crucially to the identification of their mother node.

There are also general constraints on paradigmatically connected units, such as markedness:

(3) MARKEDNESS: Within a class of elements, some are more marked than others.

In general, unmarked elements are formally and functionally simpler than marked ones, they have a wider distribution and occur in neutralization contexts (cf. Greenberg 1966). A graphematically relevant phonological example is that non-coronal sounds are more marked than coronal sounds (see Section 5.4 below).

So far we have discussed only formal constraints, but an important fact about language is that it is functional. This means that the units and structures of one subsystem, or level, stand in a systematic relationship with the units of another linguistic level, such as phonology and phonetics, syntax and semantics, etc. Two functional constraints are particularly relevant for the topic of this paper: CONSTRUCTIONAL ICONISM and COMPOSITIONALITY. Cf. (4) first:

(4) COMPOSITIONALITY: The function (e.g. meaning) of a complex unit is determined solely by the function of its parts and the way they are concatenated.
ORDERING as a special case: the (spatial or temporal) ordering of linguistic units is functional (e.g. *ab* and *ba* may serve different functions, i.e. count as distinct units).

Compositionality has been formulated for logical semantics, but its domain of application is much wider. What we expect then is that the function of a letter is determined by the function of its parts and the way they are concatenated. Ordering is the most obvious special case of a concatenation contrast and has different modality-specific manifestations. In speech, elements are aligned in temporal succession. In the spatial modality of writing, ordering has at least two dimensions: vertical and horizontal. Therefore, the term *orientation* is a better choice for the written modality.

A recurring phenomenon in language is iconism (cf. Haiman 1983). Iconism relates to the fact that there is a similarity (e.g. structural homo- or isomorphism) between sign and signatum. Iconic ordering is a good example. Thus, for instance, the spatial sequence of letters mirrors the temporal succession of the corresponding sounds (cf. Venezky (this volume) for violations of this constraint). More pertinent to our topic is constructional iconism:

(5) CONSTRUCTIONAL ICONISM:
Weak version: If *a* is more marked than *b*, and if *a′* encodes *a* and *b′* encodes *b*, then *a′* is also more marked, e.g. more complex, than *b′* (cf. Mayerthaler 1980).

> Strong version (monotonicity): If *a* has an additional marked feature that *b* lacks (all other features being equal) and if *a′* encodes *a* and *b′* encodes *b*, *b′* is properly included in *a′* (cf. Wunderlich & Fabri 1995).

Given the fact that [Plural] is a marked feature that a singular form lacks, German verbal inflection shows iconic monotonicity in *er warf* 'he threw' vs. *sie warf-en* 'they threw'. Constructional iconism is frequently found in morphology. The MRA-letters are made of syntagmatically concatenated smaller units. Loosely speaking, they resemble morphemes rather than phonemes (cf. Watt 1980: 8, Watt 1988: 251). Unsurprisingly, there is an impressive amount of constructional iconism in the MRA-system (cf. Section 5 below.).

The general principles are formulated above as optimality-theoretic constraints, for the obvious reason that they are violable in both spoken and written language. Thus, for example, coordination violates the asymmetry stated in Dependency, while idioms and lexicalized compounds violate Compositionality. Another issue is whether such constraints characterize language to the exclusion of other semiotic or cognitive systems. There is no definitive answer available at the present. It suffices to bear in mind that they are not modality-specific.

Orthographies have been criticized for mapping spoken language imperfectly. But functional imperfection is a natural trait of language. This means that a mapping between $a \in$ A and $b \in$ B, where A and B are two distinct linguistic levels that stand in a functional relationship, is not always a one-to-one correspondence or a complete structural isomorphism. One of the most obvious sources of functional imperfection is that linguistic units and representations serve various functional constraints that may compete with each other. Thus, for example, phonological features do not only correspond to phonetic features, but also have a lexical distinctive function. Furthermore, phonological features are motivated intrinsically by phonological rules. These multiple functions lead to functional imperfection in relation to the phonetic system: not all phonetic features are mapped onto phonological features, and some phonological features are hard to identify phonetically. It comes as no surprise that the phonological function of a writing system is never perfect (cf. also Venezky, this volume). The source of functional imperfection lies in the fact that a writing system represents different aspects of spoken language and that the representation of spoken language is not its only function (cf. Harris 1995).

The sections to follow will show that the above-mentioned general constraints, which have been put forward for spoken language, also hold for the internal structure of MRA-letters. We will emphasize the role of dependency, compositionality, markedness and constructional iconism and will show the classificatory function of letter features. But we insist on the fact that these constraints are instantiated in a modality-specific way. We will also formulate spelling-sound correspondences in terms of features. These functional mappings are surprisingly exact, but not perfect.

3. The substance of written language

The substance of written language is clearly distinct from that of spoken language. Written characters are discrete spatial objects and not continuous temporally defined events, which form the substance of speech and sign language. As pointed out by Harris (1995: 38f.) this trait ensures that the written sign is permanent as opposed to sounds and signs, which are ephemerical. The spatial organization of letters establishes two dimensions on the vertical and horizontal axis. Another difference between sounds and letters is that letters are composed of lower-level units that co-occur in sequence like morphemes. The lower-level units of phonemes co-occur simultaneously. Alternative approaches in which features have been assigned directly to letters have neglected this basic difference as will be shown in the next section.

As in phonetics and phonology, letter features can be defined in terms of their production or perception. In phonology, articulatory features have gained wider popularity. One explanation for this fact is the motor-theory of perception and the principle of invariance (Durand 1990: 67f.; Günther & Pompino-Marschall 1996). There are cases where the acoustic signal does not contain any invariant feature, whereas the articulation involves a single, unitary gesture in the speaker's intention. The motor-theory of perception highlights this point and claims that listeners decode acoustic patterns in terms of the articulatory gestures they are familiar with as speakers. In sharp contrast to speech, the production of writing is extremely variable due to the fact that it is performed with the aid of instruments. Therefore, it is nearly absurd to claim that readers decode the visual patterns of writing by producing them mentally (Günther & Pompino-Marschall 1996: 910).

By the criterion of invariance visual features should be treated as basic (cf. also Watt 1988). The fact that the letter features of the MRA will be formulated in visual terms in this paper, e.g. lines and not strokes, is according to this criterion not unmotivated, but should not be taken too strictly for several reasons. First, the issue of invariance is very complex (cf. Durand 1990: 67f. for speech). Secondly, as shown by Watt for writing, production and perception are intimately associated. Thus, for example, a downward stroke in production has a direct counterpart in a visual vertical line. Finally, some traits of our alphabet are motivated by production constraints, as shown by Watt (1980, 1988). Therefore, the best position to adopt is the one advocated in phonology by Durand (1990), among others: distinctive features are neutral between production and perception. An appropriate neutral term for writing would be spatial, following a proposal of Harris (1995: 46).

4. Basic letter segments and their features

4.1 General remarks

In some earlier approaches (cf. Eden & Halle 1961, Althaus 1980, Scharnhorst 1988) letter segments — such as hooks, loops, circles and semicircles — are the distinctive graphematic features of the MRA. This kind of approach disconsiders minimality, i.e., many of the proposed segments are decomposable and have to be characterized by two different features. A hooked line, for instance, combines a vertical line with a horizontal semicircle. This complex segment is difficult to classify as straight or curved, vertical or horizontal.

Psychological research has often analysed letters holistically in terms of their overall shape and has assumed template matching in letter identification. Although holistic representation seems to play some role in letter identification (cf. Bouma 1971), there is also compulsive psycholinguistic evidence for a featural analysis (cf. Johnson 1981, and with particular reference to writing acquisition, Gibson & Levin 1975, McCarthy 1977, Berkemeier 1997, 1998). There are intermediate approaches (e.g. Gibson et al. 1963, Gibson 1969, Gibson & Levin 1975) that assign distinctive features to letters as a whole.

The present investigation follows Watt's approach (1975 and subsequent work). In this type of approach, MRA-letters are broken down into their basic segments, i.e. lines or dots, which are assigned spatial features. One advantage of this kind of analysis is that it can be converted into a characterization in terms of features of the letter as a whole.

Some preliminary decisions about graphematic units that are of higher complexity are in order here. Letter sequences that correspond to one sound or behave graphematically as a single unit are usually treated as one grapheme (e.g. ⟨sh⟩ in Engl. *ship*, ⟨ch⟩ in Ger. *Milch* 'milk'). This view is problematic in two respects (cf. Kohrt 1985: 441). First, it enlarges the basic inventory of a writing system, and secondly, it disregards the fact that the individual letters in such sequences are distinctive (e.g. Ger. ⟨misch⟩ 'mix' vs. ⟨milch⟩ 'milk') and do not always behave as a unit (cf. initial capitalization in *Ship* vs. **SHip*). Instead of treating such sequences as one special unit on the segmental level, one can envisage a suprasegmental solution, similar to that proposed for affricates in non-linear phonology. Di- and trigraphs that function as one unit occupy a single suprasegmental skelettal position. This suprasegmental solution has the advantage of explaining that the unity of such sequences is most obvious in suprasegmental rules such as hyphenation (e.g. *a-shes* vs. **as-hes*) in contrast to initial capitalization, which refers to individual letters. Digraphs that cannot be decomposed syntagmatically on the horizontal axis are letters with diacritics such as ⟨i, j, é, ä⟩. The diacritic will not be treated as part of the letter in the present paper.

The knotty problem for any featural analysis is that MRA consists of two rather distinct alphabets, one for lower-case letters (minuscules) and another one for upper-case letters (majuscules or capitals). The focus of the present paper lies on minuscules[5] since these are the basic variants (cf. Brekle 1994, 1999, Günther 1988). Majuscules are used only in specific contexts, for instance for the first letter of a sentence or in titles. Because of the variability of production, we are faced with the additional problem that handwritten and print variants may vary as well. In the following only the most common variants, specifically variants that are accepted as following certain educational or typographic norms (called conventional variants, for convenience), are taken into consideration. Discrepancies between variants that lead to inconclusive analyses will be mentioned explicitly.

The solution to the variation problem, which has lead some researchers (e.g. Kohrt 1985: 441f.) to refute a featural analysis from the start, is the claim that our linguistic competence enables us to discriminate linguistically relevant features from features of extra-linguistic relevance. As a consequence, letters and their basic elements are treated as abstract linguistic entities and only linguistically relevant, i.e. graphematic, features are taken into consideration. These are features and basic segments that serve to distinguish letters from each other and, more importantly, letters from other characters and subclasses of letters from each other. In other words, we are particularly interested in features that participate in inner-graphematic or functional-phonological constraints.

We will not adopt separate bracketing conventions for the graphematic and allographic distinctions, parallel to the slant vs. square brackets used in generative derivational phonology, because the model adopted here is monostratal and declarative rather than multistratal and serial-derivational. ⟨E⟩, for instance, will be treated as the angular variant of the curved forms ⟨e, Є⟩ (cf. Section 6 below).

We will start our investigation with an overview of MRA-characters and their features.

4.2 The inventory of characters and features

The core letter inventory of the Modern Roman Alphabet is listed in (6)–(7):

(6) The MRA-majuscules:
⟨A B C D E F G H I J K L M N O P Q R S T U V W X Y Z⟩
The MRA-minuscules:
⟨a b c d e f g h i j k l m n o p q r s t u v w x y z⟩

(7) An educational handwriting MRA-variant used in Germany:
⟨*ABCDEFGHIJKLMNOPQRSTUVWXYZ*⟩
⟨*abcdefghijklmnopqrstuvwxyz*⟩

We are interested in distinguishing letters from the types of characters listed in (8) on the basis of their featural organization:

(8) Digits ⟨1 2 3 4 5 6 7 8 9 0⟩
Punctuation marks ⟨., ; : — ! ? ( ) ’⟩

The first feature is connected to the spatial alignment of MRA-characters, which is shown in (9):

(9) The spatial alignment of MRA-characters

The spatial alignment uses four virtual spaces between five virtual horizontal lines (cf. Althaus 1980, Coueignoux 1981), which can be reduced to three spaces if the third line is eliminated. Thus, the space shaded for convenience forms one space which is regarded as the central space. The feature [free], whose relevance for the MRA-system has been noticed by Brekle (cf. Brekle 1994, 1995, 1999), is defined in (10):

(10) A line is assigned the privative feature [free] if and only if it extends vertically over the central space and at least one outer space.

A line that does not have these properties lacks this feature. In majuscules this feature is redundant since they are all equally long. In minuscules, the feature is visually and phonologically distinctive (cf. Section 5.1 below). The pairs ⟨i, l⟩, ⟨ɑ, d⟩ and ⟨ɑ, q⟩ are clearly distinguished by the feature [free], but whether they are minimal pairs depends on further decisions. Thus, ⟨i, l⟩ is a minimal pair only if we eliminate the dot as redundant or as not being part of the letter in the strict sense.

Simple privative features will be assigned if there is evidence for a markedness distinction (cf. Steriade (1995) in phonology). Long letters, majuscules relative to minuscules and minuscules with a free line are tentatively analysed as marked because they surpass the central space. If evidence for a markedness asymmetry is lacking at the present state of investigation, two privative features will be used (cf. (11) below).

The next features are connected to the vertical vs. horizontal orientation of lines and are characterized in (11):

(11) A line is assigned the feature [vertical] if and only if its extension on the up-down dimension is larger than on the left-right dimension. A line is assigned the feature [horizontal] if and only if its extension on the left-right dimension is larger than on the up-down dimension. The dot lacks both features [vertical] and [horizontal].

A problem that has to be dealt with systematically is the fact that most letters lend themselves to two or more segmentation options. The minuscule ⟨e⟩, for example, might be analysed as comprising two horizontal semicircles, the top one being closed by a horizontal line, or analysed as made of a vertical semicircle with a horizontal closure. In order to reduce ad hoc decisions to a minimum, we will adhere to the following heuristical maxim: Analyse a letter in such a way as to obtain the smallest number of segments and constraint violations. By the quantitative segment-based criterion, ⟨e⟩ has to be analysed as a vertical curved line and a horizontal line. This analysis is also prompted by the constraint-based criterion, as will be shown in the next section.

The next feature captures the distinction between straight and curved lines. The privative feature [curved] will be used to capture curved lines. Straight lines are assumed to lack this feature. The decision to eliminate the binary feature [±curved] (or alternatively [±straight]) in favour of the privative feature [curved] is preliminary and implies that straight lines are unmarked and lack this additional feature. This enables us to use feature representations in which unmarked letter shapes have fewer feature specifications than marked letter shapes (cf. Steriade (1995) for this method of representing markedness in phonology).

The next issue concerns diagonal lines, as for instance in ⟨A, K, k, X, x, V, v⟩. Watt (1981, 1988) analyses / as [−Vrtcl −Hrztl] and \ as [/\ Vrtcl +Hrztl] with /\ for the null value (cf. also Gibson & Levin 1975: 16). In this analysis, ⟨A, X, x, v, V⟩ lack a vertical line and violate the verticality constraint (cf. Section 4.3 below), though both intuitively and by our definition, these letters have a clear vertical orientation. Furthermore, diagonal lines form angular figures that are in complementary distribution with the closest corresponding curved lines, e.g. ⟨ and C, their choice depending on the writing material and instrument (cf. Watt 1988). Therefore, Watt's assumption is that curvilinear forms are angular on the abstract level. Note that some conventional letter forms show this variation, e.g. ⟨A, *A*⟩, ⟨x, *x*⟩, ⟨v, *v*⟩, ⟨k, *k*⟩, ⟨y, *y*⟩. We refrain from eliminating curved forms in favour of angular ones because a curved line is phonologically functional (cf. Section 5.2 below). For this reason and for the fact that cursive variants (italics) and handwritten variants use diagonals for vertical lines in a graphematically redundant way (cf. (6) vs. (7) further above), we opt for the graphematic non-distinctiveness of diagonals instead, as stated in (12):

(12) A diagonal line is graphematically non-distinctive; it is a variant of a vertical or horizontal (mostly curved) line.

The next features are related to the feature [free]. In (10) above the feature [free] was introduced in order to assess the orientation of a minuscule on the vertical axis as short or long, i.e. free to appear in an outer space without a surrounding coda. We can refine the vertical contrasts as in (13):

(13) [free down] for curved lines: The curved line is open downwards. E.g. ⟨ſ⟩
[free down] for straight heads: The coda is at the top of the head. E.g. ⟨p⟩
[free up] for curved lines: The curved line is open upwards. E.g. ⟨j⟩
[free up] for straight heads: The coda is at the bottom of the head. E.g. ⟨b⟩

The distinction between head and coda, which will be discussed in greater detail in the next section, can be established for letters heuristically as follows: If there is only one vertical line, it is the head; among two vertical lines of different length, the longer one is the head, and among two lines of approximately equal length, the initial, i.e. left, one is the head in the unmarked case. The members in the pairs ⟨p, b⟩, ⟨q, d⟩, ⟨ſ, j⟩ and ⟨n, u⟩ are distinguished by the features [free down] vs. [free up].

The horizontal orientation of a line or letter is defined in (14):

(14) [leftwards] for curved lines: The curved line is open leftwards. E.g. ⟨j⟩
[leftwards] for straight heads: The head has the coda to its left. E.g. ⟨d⟩
[rightwards] for curved lines: The curved line is open rightwards. E.g. ⟨ſ⟩
[rightwards] for straight heads: The head has the coda to its right. E.g. ⟨b⟩

In sum, the features called *free* capture the orientation of a letter on the vertical axis, while [leftwards] vs. [rightwards] are used for the orientation of a letter on the horizontal axis. In addition, we have introduced the feature pair [vertical] vs. [horizontal] and the privative feature [curved].

To conclude this section, let us illustrate the features and their structural representation with some examples. (15a) illustrates the features of the simplest character, the dot, and (15b) that of the most simple letter, ⟨i⟩ without the diacritic:

(15) a. ⟨.⟩ b. ⟨ı⟩
[vertical]

The dot lacks any feature specifications. The letter ⟨i⟩ without the diacritic is only specified as a vertical line. It lacks any other feature. The featural analysis of the syntagmatically complex letter ⟨b⟩ is given in (16):

(16) ⟨b⟩

[vertical]	[vertical]
[free]	[curved]
[free up]	[leftwards]
([rightwards])	

This analysis can be paraphrased as follows: The letter ⟨b⟩ consists of two vertical segments. The initial segment is [free] and [free up] since the second curved segment is attached at the bottom of the line thereby opening the letter upwards and closing it downwards. The feature specification [rightwards] is bracketed because it is redundant: Once the first segment is identified as the head by its initial position and the feature [free], as will be demonstrated in the next section, the fact that the head has its coda to the right is determined by the feature structure. The head lacks the feature [curved] which means that it is straight. The second segment is [curved] and open [leftwards].

The features that have been introduced in this section are relevant on a more systematic graphematic level as they participate in inner-graphematic and functional constraints. By using features instead of letters we are able to formulate constraints that hold for classes and subclasses of MRA-letters and MRA-characters. We will start with the inner-graphematic constraints.

4.3 Inner-graphematic constraints

The inner-graphematic constraints delimit the class of letters and distinguish various types of characters from each other. We begin with constraints falling under the more general, modality-independent DEPENDENCY constraint:

(17) VERTICALHEAD: A non-vertical segment depends on a vertical line; i.e., there is no horizontal line or a dot without a vertical line.
NOVERTICALHEAD: A vertical line depends on a non-vertical segment; i.e., there is no vertical line without a horizontal line or a dot.

The dependent element will be called *coda* and the governing element will be called the *head* of the character.

VERTICALHEAD is inviolable in the subsystem of MRA-letters and digits: the head of a letter or digit is always a vertical line. Punctuation marks and diacritics have a non-vertical head, the brackets ⟨( )⟩ being the only clear exception to NOVERTICALHEAD. The comma ⟨,⟩ is not an exception to NOVERTICALHEAD if it is treated as a complex character composed of a semicircle and a dot as head of the character (cf. Bredel 2003 against this view). The marks ⟨!⟩ and ⟨?⟩ are no exception because the head of the character is the dot, both formally and functionally (cf. Bredel 2003): the dot signals the end of an utterance, which is the basic function, and the coda specifies the type of utterance.

The extended inventory of MRA-characters given in (6)–(8) above comprises separate subsystems that are defined by a specific ranking of non-parochial constraints, following a general assumption of OT. Cf. (18):

(18) Letters and digits: VERTICALHEAD >> NOVERTICALHEAD
Punctuation marks and diacritics: {VERTICALHEAD: ( )} >> NOVERTICALHEAD >> VERTICALHEAD

Individual exceptions such as ⟨( )⟩ are treated in OT either as high-ranked parochial constraints (Hammond 1995 in phonology) or by specifying the violation of the constraint in the lexical entry of the exceptional item (cf. Goldston 1996 in phonology). In this article, parochial constraints license marked features that are functionally relevant. Following ConstructionalIconism, graphematically marked features are expected to correspond to phonologically marked features. Unsystematic violations are treated as lexical idiosyncracies (cf. ⟨c⟩ as a correspondent of /k/ in Section 5).

The next constraints capture the left- or rightwards orientation of MRA-characters and fall under the more general, modality-independent Compositionality or Ordering constraint. Cf. (19):

(19) NoLeft: The character is not [leftwards].
NoRight: The character is not [rightwards].

Characters with a straight head and no coda obey either constraint (e.g. ⟨I⟩) because they lack both [leftwards] and [rightwards]. These constraints comply with the observation that every MRA-letter tends to face rightwards (cf. Watt 1983, Brekle 1999: 59f.) while digits tend to face leftwards (cf. Watt 1983). This means that MRA-letters follow NoLeft, digits NoRight in most cases, although there are violations of these constraints in both classes. The ranking differences and the parochial constraints licensing marked characters are shown in (20):

(20) Letters: {NoRight: d, j, q, g, a, u, o, …} >> NoLeft >> NoRight
Digits: {NoLeft: 6} >> NoRight >> NoLeft

The list of marked letters mentioned in the parochial constraint is tentative as some letters are difficult to analyse with regard to orientation. The letters ⟨d, j, q, g⟩ show a clear leftwards orientation because the longer segment is the head. Its orientation (e.g. ⟨j, g⟩) and the side on which the coda is attached (e.g. ⟨d, q, g⟩) define the leftwards orientation of the character (cf. (14) above). Letters that are *cum grano salis* symmetrical on the vertical axis, such as ⟨n, m, v, *x*, u, o⟩ are equivocal in this respect. If there is no functional evidence to the contrary, they will be assumed to show an unmarked rightwards orientation in compliance with NoLeft.

The next graphematic constraint establishes that codas are situated within the central space, which means that they lack the feature [free]:

(21) NoFreeCoda: The coda of a character lacks the feature [free].

This constraint is high ranked for letters. Its relevance has been established in previous research by the observation that letters are most reliably distinguished from each other within the central space (cf. Coueignoux 1981, Brekle 1994: 194, 1999: 175; Primus 2003: 29). This constraint ensures that the feature [free] contributes to the identification of letter heads.

The last inner-graphematic constraint is formulated in (22) and takes care that letter segments are properly attached to each other:

(22) Closure: Line segments forming a character are attached and oriented in such a way as to enhance the closure of the space between them.

The most obvious effect of Closure is that lines forming MRA-characters are never completely disconnected, i.e., *⟨l l⟩ cannot be a letter. Within the pairs ⟨*v*, *x*⟩ and ⟨b, k⟩ the last member is marked as exceptional with respect to Closure, a fact that is phonologically relevant (cf. Section 5.3 below). Recall that we have eliminated diagonals so that ⟨v, x, k⟩ have underlying curved lines. The curved lines of ⟨v, b⟩ face each other closing the space between them in a better way than the curved lines of ⟨x, k⟩ do. Closure is of a low rank for punctuation marks, whose segments are sometimes disconnected, cf. ⟨( ) ! ?⟩.

Leaving diacritics aside, we can summarize the classification of MRA-characters on the basis of the features, the constraints and their rankings introduced in this section as follows:

(23) The subsystems of MRA-characters and their specific constraint rankings:

<table>
<tr><td colspan="3">readable sign
VerticalHead >> NoVerticalHead
Closure >> …</td><td>non-readable sign
NoVerticalHead >>
VerticalHead
… >> Closure</td></tr>
<tr><td colspan="2">letter
NoLeft >> NoRight</td><td>digit
NoRight >> NoLeft</td><td>punctuation mark
(right-/leftwards inapplicable to horizontal heads)</td></tr>
<tr><td>minuscule
[free] distinctive
NoFreeCoda
>> …</td><td colspan="3">majuscule, digit and punctuation mark
[free] non-distinctive
… >> NoFreeCoda</td></tr>
</table>

Constraint >> … indicates a high ranking constraint, … >> Constraint a low ranking one.

After discussing the major inner-graphematic constraints on MRA-letters, we are in the position to offer the following heuristics for letter heads that follows from the relevant constraints or their property given in brackets:

(24) Head heuristics for letters: If there is only one line, it is the head (obligativity). Among two lines with a different axial orientation, the vertical one is the head (VerticalHead). Among two vertical lines

distinguished by [free], the [free] one is the head (NoFreeCoda).
Among two lines of approximately equal length, the initial, i.e. left, one is the head (NoLeft).

Since NoLeft has a fairly large number of exceptions, initial ordering is the least reliable head criterion.

In earlier research, the head-coda distinction was called vexillum-augment (Watt 1983, 1988) or hasta-coda (Brekle 1995, 1999). One problem of Watt's and Brekle's approach is that the terms hasta or vexillum and coda or augment are introduced only informally. Besides, Brekle's hasta concept is restricted to straight vertical lines (cf. Brekle 1999: 59f.) so that letters such as ⟨o, s, c, z⟩ cannot be captured as having a hasta or head. Even for letters that are symmetrical on the vertical axis, such as ⟨o, x⟩, we claim that they are asymmetrical on a more abstract structural level in compliance with Depedency: one segment is the head and the other the coda.

There is extra-graphematic evidence for the relevance of some of the features and constraints proposed here. Leftwards vs. rightwards orientation plays an important role in letter recognition (Kolers & Perkins 1969), writing acquisition (Watt 1983) and diachronic adaptation (Brekle 1999). Extra-graphematic evidence for our head concept and our head-initial analysis of unmarked letters seems to be lacking, *prima facie*. As demonstrated experimentally by Kolers (1983), among others, the right half of a MRA-letter contributes more to its identification than its left half. On the basis of such evidence, Brekle (1999: 55f.) concluded that the coda is the decisive element of a letter. We are now in the position to state the contribution of head and coda more precisely: The properties of the head have a systematic relevance, as has been shown above and as will be shown below in a functional-phonological analysis. The dependents (codas or augments) play an important role in discriminating individual letters from each other. Unsurprisingly then, codas have been shown to be crucial in tasks pertaining to the identification of individual letters.

In sum, MRA-letters are characterized by three basic properties: They must include a vertical segment, have a canonical rightwards orientation and are properly closed. Furthermore, MRA-letters comply with the general Dependency constraint: the head of a letter is the only obligatory element on which codas depend on. Following Compositionality, the role of a character within the extended MRA-system is determined by the properties of its parts and the way they are concatenated.

So far, we have analysed letters in purely graphematic terms. The next section is devoted to the phonological function of letter features.

5. Functional constraints

There is a caveat that should be kept in mind when dealing with the phonological value of a graphematic feature. The following analyses will consider only the canonical phonological function of a MRA-letter. It is the function that is dominant cross-linguistically in phonologically transparent writing systems that use the MRA. Languages with a large amount of historically and morphologically determined spellings, such as English, will be captured in a less exact manner than languages with a phonologically more transparent spelling, such as German or Italian (cf. Borgwaldt et al., this volume, for this distinction). Some of the following observations will be restricted to the writing system of German. This limitation has purely practical reasons and should be overcome in future research.

5.1 Free heads and sonority

Brekle (1994, 1995, 1999) has shown that the development of cursive writing, which culminated in the Carolingian hand and the MRA-minuscules, was guided by the free hasta and coda principle. By this principle, MRA-minuscules preferably have a free, i.e. long vertical line that is not fully encompassed by a coda. Brekle is not concerned with the phonological function of letters, but without taking this function into consideration, there is no systematic explanation for the rather numerous violations of his free hasta and coda principle. The exceptions are explained by Brekle by various factors in a rather ad hoc way. The shortness of ⟨i⟩, for instance, which had long variants in Roman times, is explained by the existence of ⟨l⟩ and the danger of confusing these two letters (Brekle 1999: 222). This observation is correct but does not answer the question why ⟨l⟩ has retained its length in contrast to ⟨i⟩ (cf. Section 5.5 for a solution).

Independently from Brekle, Naumann (1989: 194f.) dealt with the phonological function of long minuscules in German and claimed that they serve to represent phonological obstruency iconically by graphic obstruency. As shown in (25) for the native inventory of German, the ratio of graphematic units containing a free head to those lacking this feature decreases with the decrease in obstruency and the correlating increase in sonority of the corresponding sounds from (25a) to (25d).

(25) (a) letters for plosives: ⟨p, t, k, b, d, g, q⟩
(a)–(b) letters for plosive+fricative: /ks/–⟨x⟩, /ts/–⟨z, ʒ⟩

(b) letters for fricatives: ⟨f, ß, j, h, ch, sch; s, v, w⟩
(c) letters for sonorant consonants: ⟨m, n, r; l⟩
(d) letters for sonorant vowels: ⟨a, e, i, o, u⟩

The letters ⟨c⟩ and ⟨y⟩ are excluded because they are non-native in German. Naumann's observations from above can be captured by the constraints in (26)–(27):

(26) Free/Obstr (Sonor/¬Free): Graphematic units containing a free head are mapped to obstruents (sonorants, i.e. non-obstruents, are mapped to graphematic units lacking this feature). Violations: ⟨l⟩; ⟨y⟩ used natively for a vowel (e.g. Czech, Swedish).

(27) ¬Free/Sonor (Obstr/Free): Graphematic units lacking a free head are mapped to sonorants, i.e. non-obstruents (Obstruents are mapped to graphematic units containing a free head). Violations: ⟨s, z, x, v, w⟩, but not ⟨y⟩ and ⟨w⟩ used for a glide as in English.

The functional constraints are unidirectional implications. The first feature is the input; the second feature is the output. The constraints will be formulated from spelling to sound in the subsequent sections. The opposite direction that follows logically by contraposition, i.e. (A→B) ↔ (¬B→¬A), is mentioned in brackets in (26)–(27), for convenience.

The short letters ⟨s, z, x, v⟩ as well as ⟨c, w⟩ in writing systems using these letters in the native inventory to represent fricatives or sounds with a fricative component (affricates) are exceptional. As will be shown in Section 5.2 below, fricativity is systematically encoded by a curved head. As a consequence, all these letters are basically curved. Their semicircular head explains their exceptional shortness: As noted by Brekle (1999), such segments have resisted the change into a free hasta, in general. As for the exceptional length of ⟨l⟩, this element proves to be optimal in competition with its rivals (cf. Section 5.5 below).

The presence or absence of a free head establishes vertical contrasts in a letter sequence, e.g. ⟨to, go, bed⟩, and plays a role in the organization of the graphematic syllable (cf. Naumann 1989: 194f., Primus 2003: 28f.). The closely related features [free down] and [free up], defined in (13) further above and repeated in (29) for convenience, have a similar sonority function, as stated in (28):

(28) A letter with the head feature [free down] represents a less sonorous sound (FreeDown/MinSon); a letter with the head feature [free up] represents a more sonorous sound (FreeUp/MaxSon).

(29) [free down] for curved lines: The curved line is open downwards.
[free down] for straight heads: The coda is attached at the top of the head.
[free up] for curved lines: The curved line is open upwards.
[free up] for straight heads: The coda is attached at the bottom of the head.

The constraints make the most reliable predictions for pairs that are *cum grano salis* distinguished only by mirroring. The pertinent data are shown in (30):

(30)

	FreeDown/MinSon	FreeUp/MaxSon
Sonorants	Sonorant consonant	Vowel
	⟨n⟩ ⟨r⟩	⟨u⟩ ⟨i⟩
Obstruents	Unvoiced	Voiced
	⟨p⟩, ⟨q⟩ ⟨ſ⟩, ⟨f⟩, ⟨t⟩	⟨b⟩, ⟨d⟩ ⟨j⟩, ⟨*l*⟩

The pair ⟨*i*, r⟩ is somewhat equivocal because ⟨*i*⟩ lacks a coda in non-cursive variants and because it has a diacritic that destroys the mirror effect, at least superficially. But recall that a diacritic is not considered to be part of the letter. The weakest assumption is that ⟨r⟩ has the feature [free down] and lacks the feature [free up] while ⟨i⟩ has both features. In any event, ⟨i⟩ complies with FreeUp/MaxSonor. If one takes mirroring with a grain of salt, then ⟨f, j⟩, ⟨f, *l*⟩ and ⟨ſ, *l*⟩ are further corroborating data. It is also plausible to include ⟨t⟩ in this schema on the basis of the assumption that the coda is attached at the top of the head (cf. the majuscule ⟨T⟩).

As an interim result, we conclude that the graphematic representation of the sonority scale is surprisingly systematic, as shown in (31):

(31) The graphematic representation of the phonological sonority scale (reduced version)

increasing sonority →			
Free/Obstr		¬Free/Sonor	
FreeDown/MinSon	FreeUp/MaxSon	FreeDown/MinSon	FreeUp/MaxSon
⟨p, q⟩ ⟨t, f, ſ⟩	⟨b, d⟩ ⟨j⟩	⟨n⟩ ⟨r⟩	⟨u⟩ ⟨i⟩

We will refine the phonological correspondences and the graphematic representation of the sonority scale by introducing the phonological function of head curvilinearization in the next section.

5.2 Head curvilinearization and phonological constriction

When assigning the feature [curved] to letter heads, the following observations have to be taken into consideration. With free heads the curvature is part of the head as in ⟨j, f⟩, because the curvature lies in the outer space where [free] is established. But there is no reason to analyse the head of cursive ⟨*i, t*⟩ as graphematically [curved]. Note that the curvature of ⟨*i, t*⟩ does not have to be analysed as part of the head and that cursive variants are more curved than print variants anyway.

The head-feature [curved] corresponds to the degree of phonological constriction. In order to capture the homogeneity of the phenomenon for vowels and consonants we adopt the constriction model of Clements & Hume (1995). A maximal constriction in a vowel corresponds to the traditional feature [high], a minimal constriction to [non-high]. With consonants, the contrast corresponds to the distinction between non-continuants and continuants, i.e. fricatives. Curved heads represent a minimal constriction (Curved/MinConstr), heads lacking this feature represent a maximal constriction (¬Curved/MaxConstr). Cf. (32):

(32) Curved/MinConstr and ¬Curved/MaxConstr

Graphematic head-features	**Phonological features**	**List of letters**
[vertical]	maximal constriction, i.e. [non-continuant] or [high]	⟨t, d, p, b, k, q, m, n⟩ ⟨i, u⟩
	questionable	⟨l, r, h⟩
[vertical]-[curved]	non-maximal constriction, i.e. [continuant] or [non-high]	⟨s, *x*, sch, ch, f, *v*, *w*, j⟩ ⟨e, a, o⟩
	questionable	⟨c, g, *x*⟩

Letters with diagonals, which are non-distinctive (cf. (12) above), are given in their rounded cursive form. The German graphematic affricates ⟨sch⟩ for /š/ and ⟨ch⟩ for /ç/ or /x/ are introduced for illustrative purposes in order to show that the analysis can be extended to cover such cases under the plausible assumption that the first letter or segment is the head of the construction. The rounded shape of ⟨*w*⟩ legitimates its use as a fricative in German. The letter variants ⟨ſ, *ʃ*⟩, historically obsolete shapes for /s/, are additional corroborative evidence for the systematicity of the distinction under discussion.

Some letters require a comment. The letters ⟨l, r⟩, whose upper-case variants ⟨L, R⟩ also lack a curved head, represent liquids, which are traditionally classified as continuants. But Chomsky & Halle (1968: 318), for instance, admit that this analysis is not straightforward because liquids are articulated with a partial closure in the centre of the oral cavity, which is intermittent for the trilled variant of [r]. Therefore, the solution adopted in this paper is to assume that the central closure is graphematically relevant. Another solution is perhaps the fact that continuancy in sonorant consonants can be derived from nasality: non-nasals are continuant, nasals are non-continuant. The nasality contrast (cf. (39) below) is expressed graphematically by head reduplication, cf. ⟨l, r⟩ vs. ⟨n, m⟩.

The letter variants ⟨h, H⟩ represent canonically /h/, a phonologically highly equivocal sound. It is classified as a laryngeal without a bucal place of articulation in recent research (Clements 1985, Steriade 1995) or as a laryngeal fricative in traditional approaches. The non-curved head fails to express fricativity, but it is a good indicator of a syllable onset. The laryngeal is licensed only in simple syllable onsets, preferably word initially in German, for instance. If the maximal obstruency of an ideal onset is taken as the functional basis for the shape of ⟨h, H⟩, then a non-curved free head is a very good choice. This explanation is corroborated by its mute function in several languages such as French, German, Spanish and Serbocroatian (e.g. Fr. ⟨horrible⟩ 'horrible', Ger. ⟨gehen⟩ 'go' hyphenated as ⟨ge-hen⟩).

As for ⟨c⟩, which emerged from a rounded variant of Greek gamma (cf. Jeffery 1990), it continued to represent a velar stop in Ancient Roman times (cf. Allen 1965). This phoneme had anterior allophones in anterior environments, where it changed into an affricate in some languages (cf. Italian *cento, città*) or into a fricative in other languages (cf. French *cent, cité*). Only the latter phonological function is in full conformity with the curved head of ⟨c⟩. The shape ⟨C⟩ is also attested as a 'lunate' variant of Greek sigma ⟨Σ⟩ which represented the voiceless coronal fricative (cf. Threatte 1996: 274). This phonological function is still preserved in the Cyrillic alphabet. In sum, a plausible assumption is that the coronal fricative is the basic function of ⟨c⟩ in MRA. This is motivated independently by its simple unmarked form, which is not found in letters representing velar stops (cf. Section 5.3 and 5.5 below).

The upper-case variant ⟨G⟩ of the letter ⟨g⟩ emerged before the minuscule from ⟨C⟩ in Ancient Roman times and represented a voiced velar stop (cf. Allen 1965). This phoneme had anterior allophones in anterior environments, where it changed into an affricate in some languages (cf. Italian *giraffa, gente*) or into a fricative in other languages (cf. French *girafe, gens*). Only the latter phonological function is in full conformity with the curved head of ⟨g⟩. In sum, ⟨c, g⟩ pose similar problems which can be dealt with by assuming a fricative component as the canonical phonological function of these letters.

The letter ⟨*x*⟩ poses a different problem. Its canonical phonological correspondent is a plosive+fricative cluster. This also holds for ⟨z,ʒ⟩ in German. We assume that the head of these letters does not represent the plosive component, neither by a long head, with the exception of ⟨ʒ⟩, nor by a straight one.

When judging equivocal cases, one should bear in mind that the form of letters have been shaped naturally in a long process of diachronic adaptation by phonological decisions which are impressionistic and non-scientific, i.e. by naive phonetics and phonology. Unsurprisingly, the classification of sounds that seems to form the basis of graphematic adaptations does not always coincide with the classification found in modern scientific phonology and phonetics. Nevertheless, we should be particularly careful with questionable cases and look for an independent motivation, as done above.

The graphematic contrast in terms of head curvilinearization is distinctive yet in another respect in the writing system of German (cf. Primus 2003), as stated in (33) and (34) on a featural basis:

(33) Letters with the head feature [vertical]-[curved] that represent vowels in other contexts are non-phonographic (mute) in the nuclear C-Position.
Examples: ⟨viel⟩ /fi:l/ 'much', ⟨See⟩ /ze:/ 'lake', ⟨Saat⟩ /za:t/ 'seed', ⟨moor⟩ /mo:r/ 'swamp'.

(34) Letters that lack the head feature [vertical]-[curved] and represent vowels are phonographic in the nuclear C-Position.
Examples: ⟨Mai⟩ /mai/ 'May', ⟨rau⟩ /rau/ 'rough', ⟨Heu⟩ /hɔy/ 'hay'.

The assumption that German has a nucleus branching into a V-position and a C-position is transferred from phonology (cf. Wiese 1996) to the writing system (cf. Primus 2003). The constraints (33)–(34) are inviolable with the exception of proper names of dialectal origin, such as *Troisdorf* [tro:sdɔrf] and *Broich* [bro:x]. But note that idiosyncratic spelling is tolerated in proper names in other respects as well.

We are now in the position to refine the graphematic representation of the sonority scale, as shown in (35):

(35) The graphematic representation of the sonority scale (extended version)

<table>
<tr><td colspan="7">——— increasing sonority ———→</td></tr>
<tr><td colspan="4">Free/Obstr</td><td colspan="3">¬Free/Sonor</td></tr>
<tr><td colspan="2">¬Curved/ MaxConstr</td><td colspan="2">Curved/MinConstr</td><td colspan="2">¬Curved/MaxConstr</td><td rowspan="2">Curved/ MinConstr</td></tr>
<tr><td>FreeDown/ MinSon</td><td>FreeUp/ MaxSon</td><td>FreeDown/ MinSon</td><td>FreeUp/ MaxSon</td><td>FreeDown/ MinSon</td><td>FreeUp/ MaxSon</td></tr>
<tr><td>⟨p, q⟩
⟨t⟩</td><td>⟨b, d⟩</td><td>⟨f, ſ⟩</td><td>⟨j⟩</td><td>⟨n⟩
⟨r⟩</td><td>⟨u⟩
⟨i⟩</td><td>⟨e, a, o⟩</td></tr>
</table>

Some letter pairs, such as ⟨t, d⟩, ⟨v, w⟩, ⟨f, w⟩, ⟨s, z⟩, represent voice distinctions in a less systematic way. We will turn back to them in (39) below. In terms of vertical free features, ⟨c⟩ without free features, ⟨k⟩ [free up], and ⟨g⟩ [free down] — or, alternatively, neither [free down] nor [free up] — are unsystematic. The problem posed by ⟨l⟩ and its solution will be deferred to Section 5.5 below.

So far we have discussed phonological features that are related to sonority distinctions. We turn now to the graphematic representation of the basic distinction in terms of place of articulation.

5.3 Marked orientation and postalveolar articulation

The basic phonological distinction in terms of place of articulation is that between anterior or front and postalveolar or back. We will express this contrast by the privative phonological feature [postalveolar]. Phonemes with an anterior place of articulation are unmarked and lack this feature. This complies with cross-linguistic distributional evidence for /i/, a front vowel, and /t, s/, anterior, coronal consonants, being the least marked sounds (cf. Hall 2000: 81–85).[6] In agreement with Constructional Iconism (cf. also the next section), the marked feature [postalveolar] is expressed by a marked orientation on the left-right dimension. This means that head or coda are a licensed violation of NoLeft or Closure. The functional constraint is abbreviated as IconPlace. Cf. (36):

(36) Icon-Place for [postalveolar]

Attachment of coda	Closure and NoLeft obeyed	licensed violation of Closure or NoLeft
Phonological feature		[postalveolar]
	⟨b, p, t, c, f, v, w, r, l, s, n, m⟩ ⟨i, e⟩	⟨q, g, k, j⟩ ⟨a, u, o⟩
Violation of Icon-Place licensed by Icon-Voice	⟨d, z, ʒ⟩	
Questionable	⟨h⟩	⟨x⟩

The letters ⟨s, z⟩ are superficially difficult to analyse in terms of orientation, but the leftwards oriented variant ⟨ʒ⟩ is conclusive in this respect. It seems then that the upper half of the variants ⟨s, z⟩, i.e. the initial part of the stroke in kinemic terms, is decisive. If this analysis is accepted, ⟨s⟩ is rightwards oriented and ⟨z⟩ leftwards. A plausible explanation for the marked orientation of ⟨d, z⟩ is that these forms must indicate voice in an obstruent by a marked feature, i.e. ⟨t, d⟩, ⟨s, z⟩, as will be demonstrated below in (39). This means that the violation of Icon-Place is justified by Icon-Voice.

Some further letters require a comment. The letter ⟨x⟩ canonically represents /ks/, a cluster with inconsistent place properties. The anterior fricative is signalled by the curvature of the head, the velar component is signalled by the marked orientation of head and coda leading to a Closure violation. The problems posed by ⟨h⟩ for the laryngeal and by ⟨c⟩ for /k/ were discussed in the preceding section.

What needs to be discussed as well is the orientation of the letters representing postalveolar vowels. The cursive variant ⟨*a*⟩ is more equivocal than its non-cursive variant ⟨a⟩. If one analyses the initial, curved segment of the cursive variant as the head, then the minimal constriction of its phonological correspondent is captured better than its postalveolar place of articulation. If the second, straight segment is the head, the place of articulation is transparently coded to the detriment of the constriction feature. As to ⟨o⟩, its symmetric shape makes it difficult to identify the head of the letter, whereas the leftwards orientation of ⟨u⟩ is very subtle but quite obvious in comparison with its mirror image ⟨n⟩.

In letters representing vowels, rounding is not expressed graphematically by a separate device because it is an epiphenomenon of back articulation in non-low vowels (cf. Chomsky & Halle 1968: 405). This means that the graphematic marked orientation also signals rounding in non-low vowels, i.e. /u/ and /o/.

5.4 More constructional iconism

Iconicity in terms of place features, Icon-Place, was already established in the preceding section. Here we can add the fact that rounding in front vowels is a marked feature (cf. Chomsky & Halle 1968: 405), so that we can extend (36) above such as to cover writing systems that use letters for rounded front vowels, e.g. German. In addition, a low front vowel, such as [ɛː] whose only graphematic correspondent is ⟨ä⟩ in German, is also marked. Cf. (37):

(37) Icon-Place in the German inventory of vowels

Phonological feature	unmarked	[back], i.e. [post-alveolar]	[low] & [front] or [round] & [front]
Graphematic feature	unmarked	marked orientation	marked orientation and marked diacritic
	⟨i, e⟩	⟨a, u, o⟩	⟨ä, ü, ö⟩

In agreement with the strong version of monotonic iconicity, the addition of a marked phonological feature is expressed graphematically by the addition of a marked graphematic feature. Thus, for instance, the head of ⟨i⟩ is properly included in ⟨u⟩, and ⟨u⟩ is properly included in ⟨ü⟩.

The inventory of letters representing consonants is larger and less systematic, but nevertheless, the iconicity in terms of place features and nasality can be refined, as shown in (38):

(38) Icon-Place and Icon-Nasal for consonants

Phonological markedness	unmarked: anterior, coronal	more marked: anterior, [labial]	most marked: [post-alveolar], [dorsal]
non-nasal unvoiced plosive fricative	 ⟨t⟩ ⟨c, ſ⟩	 ⟨p⟩ ⟨f⟩	 ⟨q, k⟩ ⟨j⟩
non-nasal sonorant	⟨r, l⟩		
[nasal]	⟨n⟩	⟨m⟩	⟨ng⟩

In order to control intervening factors, sounds which only differ in place of articulation are directly evaluated. Only the phonological privative features appear in brackets that contribute to an increase in markedness. The unmarked feature values are added for convenience without brackets. The perfectly iconic correspondent of a coronal fricative, ⟨ſ⟩, is a historically obsolete form. The shape of ⟨c⟩ is too short for an obstruent, otherwise it would be perfect for a coronal fricative (cf. Section 5.5 below). As mentioned before, this function is found only in specific contexts in some writing systems that use the MRA. The letter ⟨s⟩, which is canonically used for the coronal fricative, is somewhat more complex than expected.

Nasality, which is a phonologically marked feature (cf. Chomsky & Halle 1968: 405, Steriade 1995: 119), is expressed by head duplication for the coronal and head triplication for the labial, which is additionally marked for place. The velar nasal, the most marked nasal, is represented by a digraph in German.

Another well-known marked feature is voice in obstruents (cf. Chomsky & Halle 1968: 406, Steriade 1995: 155). One way of representing sonority distinctions in general and voice distinctions in particular is by means of the features [free up] vs. [free down] in pairs distinguished by mirroring (cf. (30)–(31) above). In (39) an overview of the less systematic pairs is offered:

(39) Icon-Voice in obstruents

	[obstruent]	[voice]-[obstruent]	marked or additional graphematic feature
Coronals	⟨t⟩	⟨d⟩	marked orientation
	⟨s⟩	⟨z, ℨ⟩	marked orientation, horizontal coda
Labials	⟨P⟩	⟨B⟩	coda reduplication
	⟨f⟩	⟨v⟩	head reduplication, short head for obstruent
	⟨v⟩	⟨w⟩	head reduplication
Velars	⟨q⟩	⟨g⟩	coda reduplication

The minuscules ⟨p, b⟩ need not represent the voice opposition by a marked coda since it is expressed by [free down] vs. [free up]. The letters ⟨v, w⟩ are used for a fricative pair distinguished by voice only in some languages, e.g. German. In German, the pair ⟨s, z⟩ does not express a voice distinction, but rather a fricative vs. affricate opposition. This also satisfies iconism.

Some graphematic markedness asymmetries, expressed by the privative features [free] and [curved], for instance, do not have clear-cut phonological correspondents. The first feature expresses obstruency, the second fricativity. There is no evidence for the marked status of these phonological features.

The instances of iconism discussed above hold across the visual and auditive modality, but letter shapes may also mirror articulatory gestures in purely visual terms. The fact that phonological maximal constriction is expressed by a straight head, while minimal constriction by a curved one, and not the other way round, is explicable by the visual shape of the mouth in articulating this contrast. The shapes of ⟨i, e, ɑ⟩ are particularly good examples that vizualize an increased opening from ⟨i⟩ to ⟨ɑ⟩. The fact that obstruency is expressed by a long head is another instance of visual iconism. Finally, the fact that letters for velars, ⟨j, q, g⟩ for instance, have their head on the right hand side mirrors the raised back part of the tongue; coronal consonants show the reverse configuration, congenially expressed by the shape of ⟨r, ſ, *t*, *l*⟩. Recall that in the standard view of the articulatory apparatus the front articulators are on the left and the back ones on the right.

5.5 Exemplary evaluations

As a summary of Section 5, we will offer some exemplary analyses of letter shapes in both directions of fit: from letter to sound and from sound to letter. The evaluations in (40)–(43) take the graphematic feature specifications of the respective letter as input and sound features as output candidates. The tableaux comprise several evaluations, one for each input feature specification. The winning candidates form a phonological feature bundle that defines a phoneme or a subclass of phonemes.

(40) Evaluation of the optimal phonological correspondent of ⟨e⟩

	¬Free / Sonor	Curved / Min-Constr	Icon (unmarked)
Input: ¬[free]			
obstruent	*!		
☞sonorant			
Input: [curved]			
max constr		*!	
☞min constr			
Input: [rightwards], unmarked closure			
postalveolar ⇒ round			*!
☞¬postalveolar ⇒ ¬round			

Let us introduce the OT methodology first. Constraints are aligned in a tableau from left to right as stated in the ranking hypothesis of the respective linguistic system. We are dealing with constraints that do not compete with each other and that are therefore of equal rank. They are separated by dotted lines in the tableau. If a candidate *x* violates a constraint and there is another candidate *y* that does not violate it, *x* has a fatal violation (cf. *!) and is eliminated from the competition. The winner is the candidate (cf. ☞) that has the smallest number of violations of the highest relevant constraint. In our case the winner does not violate any constraint.

The evaluation in (40) establishes that the subclass of phonemes represented by the graphematic features of ⟨e⟩ is characterized by the phonological feature bundle [sonorant, minimal constriction, non-postalveolar, non-round]. Minimal constriction means that the phoneme is either a fricative or a non-high vowel. Since a fricative is an obstruent, it is eliminated by ¬Free / Sonor. The unmarked value for front vowels is non-round, and since the shape of ⟨e⟩ is unmarked, the phonological value must be unmarked as well, as determined by the Icon-constraints. In sum, the graphematic features of ⟨e⟩ correspond to the bundle of phonological features that define a subclass of phonemes represented as /e/ or /ɛ/. This is indeed the phonological value in the phonologically transparent spellings of the most writing systems that use the MRA.

The next tableau evaluates the phonological value of the input shape ⟨j⟩. Cf. (41):

(41) Evaluation of the optimal phonological correspondent of ⟨j⟩

	Free / Obstr	Curved / Min-Constr	Icon (marked [leftwards])	FreeUp / MaxSon
Input: [free]				
☞obstruent				
sonorant	*!			
Input: [curved]				
max constr		*!		
☞min constr				
Input: [leftwards]				
☞postalveolar				
¬postalveolar			*!	
Input: [free up]				
min sonor				*!
☞max sonor				

The result of the evaluation is the phonological feature bundle [obstruent, minimal constriction, postalveolar, max sonorous], i.e. a voiced postalveolar fricative such as /j/ in German *ja* 'yes' or /ž/ in French *jour* 'day'.

The tableaux (42)–(43) deal with ⟨c⟩, a more problematic case.

(42) Evaluation of the optimal phonological correspondent of ⟨c⟩

	¬Free/ Sonor	Curved/ MinConst	Icon (max unmarked)
Input: ¬[free]			
obstruent	*!		
☞sonorant			
Input: [curved]			
max constr		*!	
☞min constr			
Input: [rightwards], unmarked closure			
postalveolar			*!
☞¬postalveolar			

The result of the evaluation yields the same winner as in (40): a front, non-round, non-high vowel. This is a near miss because the shapes of ⟨e⟩ and ⟨c⟩ are very closely related. In order to improve the prediction, we need to introduce a parochial constraint above ¬Free/ Sonor. Cf. (43), in which further features that are distinctive for obstruents are added:

(43) Revised evaluation of the optimal phonological correspondent of ⟨c⟩

	¬Free & curved / Obstr {c, s, ʋ, …} >> ¬Free/ Sonor	Curved/ MinConst	Icon (max unmarked)
Input: ¬[free] & [curved]			
☞obstruent			
sonorant	*!		
Input: [curved]			
max constr		*!	
☞min constr			
Input: [rightwards], unmark. closure			
postalveolar			*!
☞¬postalveolar			
Input: simplest shape			
¬coronal, voice			*!
☞coronal, ¬voice			

The evaluation in (43) runs as follows. The short semicircular head of ⟨c⟩ licenses a violation of ¬Free / Sonor. This means that despite its shortness, this head signals an obstruent. The curvature of the head predicts minimal constriction, i.e. a fricative, and the simple shape tells us that it must be a maximally unmarked, i.e. unvoiced coronal, fricative, namely /s/. As discussed above in greater detail, this phonological function of ⟨c⟩ is attested in many languages that use the MRA. The value /k/, which is also very common, seems to be an idiosyncratic exception.

We turn now to the direction of fit from sound to letter and start with the input sound /u/ in (44):

(44) Evaluation of the optimal letter shape for /u/

	MaxConstr/ ¬Curved	Icon-Place (marked)	Sonor/ ¬Free	MaxSonor/ FreeUp
Input: max constr				
[curved]	*!			
☞¬[curved]				
Input: postalveolar				
[rightwards]		*!		
☞[leftwards]				
Input: sonorant, vowel				
[free], [free down]			*!	
☞¬[free], [free up]				

The evaluation in (44) establishes that the letter shape for /u/ must have a straight and short head with the coda attached to its left in such a way that the character is free upwards and closed at the bottom. The shape ⟨u⟩ is congenial for the purpose: it is the most economical shape that satisfies the phonological conditions. Furthermore it complies with the distinctness constraint Unique. This ensures that this shape is distinct from the other letters in the MRA-system.

The evaluation in (45) is more complex and is meant to show that the OT competition model is particularly well-suited to explain the shape of the sound /l/, whose free head seems to be a problematic feature for a sonorant. In order to simplify matters letter shapes instead of graphematic features are used.

(45) Evaluation of the optimal letter shape for /l/ — Part one

Input: consonantal sonorant, non-nasal, coronal, max constr	Icon (unmarked)	MaxConstr/ ¬Curved
⟨c⟩		*
⟨n⟩	*	
⟨j⟩	*	
☞⟨r⟩		
☞⟨*i*⟩		
☞⟨*l*⟩		

In the first step, we will restrict the candidate set to the most plausible representations of the sound /l/, namely ⟨r, i, l⟩. Let us consider iconism first. The optimal shape for a coronal non-nasal sound must be very simple and must have an unmarked orientation. As a consequence, the shapes ⟨n, j⟩ are eliminated. The set of candidates is further diminished by the constriction constraint: Because of the central closure of /l/ the head of the letter has to be non-curved so that the shape ⟨c⟩ is eliminated. The relative ranking of these constraints is not crucial for this set of data: Any ranking restricts the class of candidates to the shapes ⟨r, i, l⟩ with the sonority-related constraints deciding the competition.

(46) states the sonority-based constraints explicitly and comprises three distinct evaluations for the mappings of the three sounds /i, r, l/ to the three letters ⟨i, r, l⟩:

(46) Evaluation of the optimal letter shapes for /i, r, l/:

	I for /i/	II for /r/	III for /l/
	Sonor/¬Free MaxSon/FreeUp	Sonor/¬Free MinSon/FreeDown relative to /i/ and MaxSon/FreeUp relative to /l/	Sonor/¬Free MinSon/FreeDown relative to /i/ or /r/
a.	☞/i/–⟨*i*⟩	☞/r/–⟨r⟩	*/l/–⟨l⟩
b.	*/i/–⟨l⟩	*/r/–⟨l⟩	☞/l/–⟨r⟩
c.	*/i/–⟨r⟩	*/r/–⟨*i*⟩	*/l/–⟨*i*⟩

The three rows, I–III, have different input sounds, which are aligned according to a decrease in sonority from left to right: /i/ > /r/ > /l/. The second line lists the relevant constraints. The lines (a)–(c) in a row list the competing mappings. A violation mark is attached to a mapping if it violates one of the constraints listed above it in the same row. Thus, each row is a compact version of a standard tableau.

The mappings /i/–⟨*i*⟩, /r/–⟨r⟩ and /l/–⟨r⟩ are perfect and incur no violation. The others violate a constraint: /i/–⟨l⟩ and /r/–⟨l⟩ violate Sonor/¬Free; /i/–⟨r⟩ and /r/–⟨*i*⟩ violate MaxSon/FreeUp and MinSon/FreeDown respectively, /l/–⟨l⟩ violates Sonor/¬Free and /l/–⟨*i*⟩ violates MinSon/FreeDown. The dilemma is that given the high number of sounds with the least marked place of articulation, i.e. coronals, in the phonological system, the sign inventory is short of simple shapes.

Thus, the problem occurs that the letter ⟨r⟩ — viz. a simple shape with a straight short head that is free downwards — is optimal for two input sounds, namely /r/ and /l/, a situation that violates the constraint Unique. It requires that one sound is mapped to only one letter and one letter to only one sound.

Violations of Unique occur, but are usually harmless because the ambiguous mappings have complementary contexts of use (e.g. /y/ — ⟨ü⟩ used in the native vocabulary and /y/ — ⟨y⟩ in the non-native vocabulary of German). The mappings discussed here would violate Unique in each context of use. In order to avoid such a severe violation of Unique, one of the three winners in I-III has to give way to a suboptimal candidate. Since /l/ is the least sonorous sound in the subset, /l/-⟨l⟩ is the best suboptimal candidate in terms of Sonor/¬Free. The following subsystem emerges: the least sonorous sound is mapped to a long head, the two less sonorous sounds to a short one. In this pair, the letter for the less sonorous sound is open downwards and the letter for the most sonorous sound is open upwards, as predicted.

Other exceptional, i.e. marked letter shapes can be explained in a competition model in a similar way. The marked leftwards orientation of letters representing velars, i.e. ⟨j, q, g⟩ is a case in point: the violation of NoLeft is justified by Icon-Place. The exceptional orientation of ⟨d⟩ as opposed to ⟨t⟩ and that of ⟨z⟩ relative to ⟨s⟩ is justified by Icon-Voice.

6. Majuscules

The intrinsic graphematic and functional analyses enable us to systematize the relationship between the minuscule and majuscule variant of a letter. This is a desideratum both on theoretical grounds and in view of experimental evidence showing that subjects reported the abstract identities of letters more accurately than their status as majuscules or minuscules (cf. Friedman 1980: 58). A plausible answer to this problem is that minuscules and majuscules are derived from each other by a few straightforward majuscule- or minuscule-specific constraints.

The first notable difference between minuscules and majuscules has been captured by the notion of a free, i.e. long head. Minuscules use this feature for sonority distinctions contrastively, while majuscules are invariantly long. They have a full extension of head and coda(s) on the virtual three upper spaces. The lower space is unavailable for majuscules with the exception of some handwritten variants, e.g. ⟨*G J Y*⟩ in German educational inventories (see (7) above). This means that majuscules are by far more opaque for phonological sonority distinctions than minuscules. (47) illustrates pairs of print variants that are only distinguished by this feature:

(47) Invariant length over the three upper spaces in majuscules:
⟨c, C⟩, ⟨i, I⟩, ⟨j, J⟩, ⟨k, K⟩, ⟨o, O⟩, ⟨p, P⟩, ⟨s, S⟩, ⟨u, U⟩, ⟨v, V⟩, ⟨w, W⟩, ⟨x, X⟩, ⟨z, Z⟩

In addition, the phonologically irrelevant diacritic dot is eliminated. The next difference is the preference for intrinsical symmetry in majuscules, as shown in (48):

(48) The preference for intrinsical symmetry in majuscules:
Vertical: ⟨a, A⟩, ⟨h, H⟩, ⟨t, T⟩, ⟨y, Y⟩
Horizontal: ⟨b, B⟩, ⟨d, D⟩, ⟨e, E⟩, ⟨h, H⟩

Intrinsical symmetry means that the reflection axis lies within the letter. Some comments are in order here. The unmarked head-initial orientation of ⟨D⟩ matches the coronal value better than the leftwards oriented minuscule ⟨d⟩. The print variants ⟨l, L⟩ show the opposite symmetry distribution. The pair ⟨n, N⟩ is not an exception to the symmetry preference, if we acknowledge the point symmetry of ⟨N⟩.

The last systematic contrast is that minuscules tend to be more curved and more closed, while majuscules are more angular and more open. The correlation between curvilinearization and closure, and angularization and opening seems to hold for other alphabets as well (cf. Wiebelt 2004: 55).

(49) Angularization and opening in majuscules:
⟨a, A⟩, ⟨e, E⟩, ⟨f, F⟩, ⟨h, H⟩, ⟨m, M⟩, ⟨n, N⟩, ⟨t, T⟩

Angularization destroys the phonological transparency of the majuscules ⟨A, E, F⟩ in terms of constriction: the minimal phonological constriction of the corresponding sounds is not represented by a curved head (but note the rounded variants ⟨ᗩ, ∈⟩).

A few pairs are less systematic, notably ⟨r, R⟩, ⟨g, G⟩ and ⟨q, Q⟩. The shape of ⟨R⟩ is too complex for a coronal non-nasal sound. In the pairs ⟨g, G⟩ and ⟨q, Q⟩ the clear-cut leftwards orientation of the minuscule, which is congenial for a postalveolar sound, is obscured.

In sum, the following picture emerges. Majuscules are connected to minuscules by a few constraints, specifically [free]-neutralization, i.e. redundant length, intrinsical symmetry and angularization. These constraints are responsible for the reduced phonological transparency of majuscules. All these characteristics are in agreement with the reduced use and the ornamental function of majuscules.

7. Summary and outlook

The preceding sections have shown that the internal structure of MRA-letters is highly systematic in both inner-graphematic and functional-phonological terms. The proposed inner-graphematic constraints establish the optimal shape and internal structure of a minuscule letter and serve to distinguish letters from other MRA-characters such as digits and punctuation marks. Letters have a vertical head with an optional vertical or horizontal coda attached to it. Heads may be long (free) or short while codas are always short. The head-coda asymmetries are in compliance with the modality-independent Dependency constraint. In agreement with the general Compositionality constraint, the order of concatenated units is functional. Letters are distinguished from digits by having a head-initial unmarked order. This means that a letter faces rightwards in the unmarked case as opposed to digits, which face leftwards in the unmarked case.

As to the phonological function of MRA-minuscules, canonical orientation and proper closure correlates with front articulation. Postalveolar articulation is manifested by a marked position or marked orientation of the coda. The internal structure of MRA-letters is also in full agreement with the distinctions predicted by Markedness and with Constructional Iconism, a constraint that requires an isomorphic coding in terms of markedness. As shown above, there is an impressive amount of constructional iconism in the MRA-system. These are modality-independent characteristics of language which are expressed by specific spatial devices.

A modality-specific trait is the fact that letters show an orientation both on the horizontal and vertical axis. On the vertical axis letters are distinguished from each other by an upwards or downwards orientation and by their length on the vertical axis. The vertical contrasts encode sonority distinctions. The horizontal leftwards or rightwards orientation correlates with the phonological front-back distinction.

Another modality-specific contrast is that between a straight and a curved head. This contrast is mapped to the degree of phonological constriction. This is one of the instances of a purely visual gestural iconism. The curved head mirrors the shape of the mouth in a minimal closing gesture; the straight head is an icon of maximal constriction.

Optimality Theory turned out to be congenial to the purpose of revealing the systematicity of the MRA-system. The best results are obtained by competing, violable and ranked constraints. There are both idiosyncratic, i.e.

inexplicable, and systematic, i.e. explicable violations. The shape of ⟨c⟩ for a velar stop is a good example for an idiosyncracy, at the present state of our knowledge. Systematic violations are explained in OT by the concept of competition. Thus, for instance, there are violations of the above-mentioned rightwards orientation of letters that are motivated by a competing functional constraint, specifically by constructional iconism, which requires a marked coda for the marked postalveolar place of articulation or for marked voice. Another instance of competition explains the exceptional free, i.e. long head of ⟨l⟩. The violation of the sonority constraint requiring a short head for a sonorant is motivated by the fact that ⟨l⟩ is the best choice among its immediate competitors ⟨i⟩ and ⟨r⟩.

It turned out that a feature-based correspondence yields a subclass of phonemes as output. This output may be underspecified for a particular phoneme. This means that the MRA is well adapted to synchronic and diachronic phonological variation within certain limits.

Finally, the problem of letter variation was solved on the basis of a few majuscule-specific constraints and other variation-related constraints such as the elimination of diagonals. The whole body of constraint-based assumptions has validated the traditional claim that synchronically, the minuscules are the basic variants. In our analysis they turned out to be formally more systematic and functionally more transparent than majuscules.

The most important advantage of a feature-based approach is the fact that correspondences between letters and sounds can be formulated in terms of classes of letters and sounds. This is a crucial step towards a rule-based perspective which overcomes the traditional grapheme-to-phoneme conversion "rules" pertaining to individual items and as such forming a lexicon rather than a grammar.

The results of the present investigation are promising but preliminary. The featural analysis proposed here is meant to hold for the MRA only. Future research has to establish which parts of this analysis can be carried over to other alphabetic systems and which constraints are specific for the MRA. As to the writing systems using the MRA, adequate functional-phonological constraints can only be formulated on the basis of a complete analysis of the phonological and graphematic system. For practical reasons, this has been accomplished only for German in this paper. Other systems have been accommodated only partially, leaving a gap to be filled by future research.

Notes

1. In order to capture the braille script used by blind people one could replace visual with spatial (cf. Harris 1995).

2. Sign language may, in principle, also have correspondences to the written language.

3. The scheme is simplified in as much as it focusses on substance-based (biomechanical) constraints and does not consider other modality-specific factors that may shape semiotic systems (cf. Harris 1995).

4. Recent research has demonstrated that all writing systems systematically represent phonological information (cf. DeFrancis 1989, Perfetti & Tan 1998, Sproat 2000). This also holds for Chinese and other systems that have been classified as logographic.

5. Watt (1981, 1988) analysed upper-case letters. This and the neglect of the phonological value of a feature account for most of the divergences between his analyses and mine.

6. Steriade (1995: 152) implicitly rejects this hypothesis when she claims that there is no evidence for a markedness distinction between front and back articulation.

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