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Interactions among patterns in Chinese character form*

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Abstract

In our previous work, we argued that Chinese character form is governed by a formal lexical grammar similar to the morphology and phonology of spoken and signed languages. Character morphology operates on potentially interpretable basic components (morphemes) in reduplication, semantic compounding, and semantic radical affixation. Character phonology (silent, as in sign languages) consists of uninterpretable patterns in stroke and component form, including idiosyncratic allomorphy, reduplicative identity, axis assimilation, stroke diagonalization, prominence at the bottom and right, and stroke curving at the left; all of these patterns are influenced by character prosody (asymmetric binary strong-weak structure along the horizontal and vertical axes). In this paper we study for the first time precisely how character morphology and phonology interact with each other, adopting as our formal framework Stratal Optimality Theory (OT), which posits a stem stratum that is universally ordered before a word stratum, with each stratum an ordinary OT grammar. We test six predictions of this framework in Chinese characters, including that opaque interactions are only possible when phonological patterns are associated with different morphological strata, and find a surprisingly good fit. We also find that just as in analyses of spoken and signed lexicons, prosody plays a key role in explaining problematic cases, here including an otherwise puzzling variation in stroke order. Stratal OT allows us to make a much more precise description of character structure than has been possible in the traditional literature, including new evidence that writing shares deep cognitive mechanisms with speech and signing.

Keywords: Chinese characters, grammatical theory, phonology, morphology, Stratal OT

1. Introduction

Building on a long history of analyzing writing systems as having grammars of their own (see review in Meletis 2020), Myers (2019a) argues that Chinese character components are combined in accordance with a "character morphology", that the shapes and arrangement of strokes and stroke groups conform to a "character phonology", and that both of these grammatical components are not only psychologically real but strikingly similar to those of spoken and signed languages.

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One underexplored area in this research program involves the interactions of these two subsystems with each other and with the lexicon. The lexicon would seem to be particularly important in a system as historically conservative as Chinese script. There has been little change in its morphology since the emergence of oracle bone script (甲骨文) and in its phonology since the emergence of regular script (楷書), even when we take into account the simplified system of the People's Republic of China (which we will not do here; for analyses of this system, see Myers 2019a, section 4.3.2).

The great insight of the theory of lexical morphology and phonology (Kiparsky 1982), as well as its structuralist morphophonological precursors and its most recent incarnation in Stratal Optimality Theory (Stratal OT) (Kiparsky 2015; Bermúdez-Otero 2018), is that even the lexicon is principled. Thus even if Chinese character morphology and phonology are as lexicalized as one might expect, Stratal OT should still make concrete and testable predictions about them.

I start in section 2 with a quick overview of Chinese character morphology and phonology, and then in section 3 give an even quicker overview of Stratal OT. In section 4 I test six predictions made by this theory for character form. I end in section 5 by setting the findings in a broader context.

2. Character grammar

In his analyses of writing systems, Gelb (1963) distinguishes between an "inner" aspect encoding the spoken language (e.g. letters for phonemes) and an "outer" aspect of mere physical appearance (e.g. strokes). Myers (2021b) equates the former with orthographic morphology and the latter with orthographic phonology (both silent, as in sign languages); Watt (1975) makes a similar distinction in his analysis of the Latin alphabet (each letter is a morpheme composed of phonemic strokes).

Starting our review with Chinese character morphology, Myers (2019a) argues that the analogs to morphemes are the character components (部件), since they have functional interpretations (meaning and/or pronunciation) and combine via operations similar to morphological affixation, compounding, and reduplication. These operations are summarized in Table 1.

Table 1. Morphological operations in Chinese characters

Operation	Traditional name	Examples
Affixation	形聲字	根 *gēn* 'root' = 木 'tree' + 艮 *gěn*
Compounding	會意字	相 *xiāng* 'see' = 木 'tree' + 目 'eye'
Reduplication	疊體字	林 *lín* 'forest' = 木 'tree' + [WS][a]

[a] [WS] represents a weak-strong prosodic template for horizontal doubling (see below). Note also that throughout the paper, character examples are given in a brushlike typeface; a serif typeface is used for all other Chinese text (technical terms and spoken Chinese examples).

The character analog of affixation is the adding of the semantic component (affix) to the phonetic component (stem) in phono-semantic characters (形聲字). Like affixes in spoken and signed languages, these special morphemes are bound, form a closed class, have relatively fixed positions (most commonly on the left, just as English affixes primarily prefer word-final position), and are typically reduced in size and/or stroke complexity.

By contrast, in true compounds (會意字), components have more definitive semantics than affixes: 口 represents a literal mouth in the compound 吠 *fèi* 'bark of a dog' (cf. 犬 *quǎn* 'dog') rather than merely indicating the class of function words (虛詞) as in the phono-semantic character 嗎 *ma* (question particle) (cf. 馬 *mǎ* 'horse'). Jackendoff (2010) argued that English compounds are governed more by pragmatics than by formal constraints, and similarly, compounding in characters is often iconic, including in component position: 水 'water' appears below the body in 尿 'urine' but between the hands in 盥 'wash'. This is different from affixed forms (phono-semantic characters), where iconicity seems to be irrelevant; as James Tai points out (p.c.), 汞 *gǒng* 'mercury' and 江 *jiāng* 'river' contain the same components (氵 is an allomorph of 水) but the difference in their positions merely serves to create a lexical contrast (for related discussion, see Harbour in press).

Finally, as observed by Behr (2006), reduplication (疊體字, traditionally considered a subset of 會意字) expresses the same limited range of iconic meanings as in spoken (and signed) languages, such as abundance as in 多 'many' (cf. Mandarin 人人 *rénrén* 'everybody'), intensity as in 晶 'glittering' (cf. Mandarin 憧憧 *chōngchōng* 'flickering'), and attenuation as in 弱 'weak' (cf. Mandarin 軟軟 *ruǎnruǎn* 'a little soft'). This operation is also like spoken and signed reduplication in being formally restricted to a fixed set of binary templates (McCarthy & Prince 1998) representing vertical doubling (多), horizontal doubling (弱), and triangularity (晶, binary along both axes). Experiments suggest that these templatic restrictions are part of the productive knowledge of fluent Chinese readers (Myers 2016).

Meanwhile, character phonology consists of patterns involving strokes, their positions, and their shapes (see also Wang 1983); the patterns discussed in this paper are shown in Table 2.

Table 2. Phonological patterns in Chinese characters

Pattern	Conditions	Examples	Exceptions
Axis assimilation	Within components	川, 三, 彡, 土	才, 文
Curving: Morpheme-level	Weak positions within components	川, 月, 片, 周	同, 甬
Character-level	Weak positions within characters	辣, 羚, 氘	(all other components)
Prominence	Strong positions in all environments	三, 川, 昌, 林	士, 末
Reduction: Diagonalization Dotting Shrinking	Weak positions within characters	場, 站 根, 郴 筆, 電	(none)
Stretching	Weak & strong positions within characters	起, 颱	(none)
Idiosyncratic allomorphy	Weak positions within characters	忙, 花, 刻, 照	(many)

Within individual character components, strokes prefer to be parallel and/or orthogonal, as in 川, 三, 彡, 十, 乂, 土; this pattern, found in many writing systems, is motivated by basic visual principles (Morin 2017). Myers (2019a) calls this axis assimilation, noting that it only applies within individual character components: 彡 in 形 does not become 三 or 川 in order to assimilate to the horizontal and vertical axes of the strokes in 开.

Another stroke pattern is the restriction of curving to the vertical stroke (直撇) closest to the left edge of a component, as in 川, 月, 片, 爿, 非 (cf. 非 in some styles, including the simplified system). As noted by Wang (1983), curving is obligatory in tall/narrow components like 舟, 介, 升 but not in squat/wide ones like 冊, 兩, 岡, leading to near minimal pairs like 角 vs. 甬. Experiments suggest that readers have productive knowledge of this pattern (Myers 2019a) and its relation to width (Myers 2022). Curving also targets the single vertical stroke in a small set of components anywhere in the left (non-rightmost) portion of a whole character, such as 辛, 羊, 丰, and 刂 (an allomorph of 刀 *dāo* 'knife') in 辣, 羚, 邦, and 班, respectively (cf. the lack of left-component curving in 悱 and 佛). Despite being lexically restricted, the psychological reality of character-level curving is suggested by the modern compound 氕 *piē* 'protium' (丿 *piě* 'one' + 气 'gas'; cf. 氘 *dāo* 'deuterium' and 氚 *chuān* 'tritium').

One of the most pervasive phonological patterns in Chinese character grammar is prominence, which enlarges the rightmost and bottommost element, whether this is an individual stroke within a component (三, 土, 川, 井), an orthographic "syllable" (Myers 2021a) within a component (官, 飛, 由 vs. 甲), or a whole component within a multi-component character (林, 昌, 巾 in 帥 vs. 帖, 大 in 尖 vs. 奇). Again, experiments suggest that readers seem to have productive knowledge of this pattern (Myers 2019a). Prominence can be analyzed as a kind of orthographic stress occurring in the "strong" (head) position of an orthographic foot (cf. the "visual prosody" of English and German spelling analyzed by Evertz 2018). As Myers (2019a) argues, this allows prominence to be linked to the templatic (foot-based) restrictions of reduplication and the width-sensitivity of curving. That is, narrow components have only one "foot", placing the left-edge stroke in a prosodically weak position, so the lack of morpheme-edge curving in (1b) need not be encoded via an exception diacritic but rather via its prosodic structure: if (1b) is composed of two feet, the leftmost stroke is in a strong position and so cannot be curved ([] marks foot boundaries, and W and S represent weak and strong positions, respectively).

(1) a. 角 [WS]
b. 甬 [S][S]

A number of apparently exceptionless stroke patterns are sensitive to prosody as well. These include the diagonalization of the lowest horizontal stroke (changing the 横 stroke type into the 挑 stroke type) in components other than in the rightmost position (i.e., in prosodically weak positions), as with 土 in 場, 工 in 鴻 vs. 江, and 圭 in 街. In the same context, dotting changes a falling diagonal stroke (捺) into a dot (點), as with 木 in 根 and 郴, or 矢 in 短. Shrinking applies at the prosodically weak top, turning strokes into dots (i.e., very short strokes), as with 竹 in 筆, or into hooks (鈎), as with 雨 in 電. I will collectively call these patterns reduction. Reduction also combines with prominence in a phenomenon that Myers (2019a) calls stretching, whereby the lowest diagonal stroke of a reduced left-position component is extended under the right-position component in the prosodically strong bottom position, as with 走 in 起 and 風 in 颱.

At the opposite extreme in productivity, around thirty character components are lexically marked to undergo idiosyncratic allomorphy, altering the form and/or number of strokes in ways that are predictable only to the extent that the same component typically shows the same allomorphy in the same environment. This pattern is partly prosodically conditioned, since it is most common in the weak left and top positions, as with 心 'heart' appearing as 忄 in 忙 *máng* 'busy' but as 心 in 忘 *wàng* 'forget' (cf. 亡 *wáng*; likewise 水 vs. 氵 in 汞 vs. 江 as noted above), and 艸 'grass' appearing as 艹 in 花 *huā* 'flower' (cf. 化 *huà*). However, it is also partly morphologically conditioned, since affixes (semantic components in phono-semantic characters) may undergo idiosyncratic allomorphy even in the right and bottom positions, as with 刀 'knife' as 刂 in 刻 *kè* 'carve' (cf. 亥 *hài*), and 火 'fire' as 灬 in 照 *zhào* 'shine' (cf. 昭 *zhāo*). Moreover, Myers (2019a, section 2.3.1.3) observes that in semantic compounds, idiosyncratic allomorphy is restricted mostly to the left, as with 手 *shǒu* 'hand' as 扌 in the compound 折 *zhé* 'break' (cf. 斤 *jīn* 'axe'). Phonetic components undergo idiosyncratic allomorphy even more rarely, and again when they do it is generally in the weak position at the left, as with 示 *shì* in 視 *shì* 'look', or top, as with 卯 *mǎo* in 貿 *mào* 'trade'.

A notable exception to both prosodic and morphological conditioning is the high-frequency morpheme 刀 *dāo* 'knife', which adopts its idiosyncratic allomorph 刂 in the right position even in semantic compounds like 利 *lì* 'profit' (cf. 禾 'grain') and as a phonetic component as in 到 *dào* 'to'. Since idiosyncratic allomorphs are always "light" (reduced in size, number of strokes, and/or stroke complexity), Myers (2019a, section 3.3.1.1) suggests that when they appear at the right or bottom they may be extraprosodic (i.e., the prosodic structure of 到 is [S]W rather than [WS] or [SW]). However, as admitted in Myers (2019a, section 3.4.5), this analysis causes a problem, as shown by characters like 判 *pàn* 'distinguish' and 邦 *bāng* 'state', which have idiosyncratic allomorphs on the right (刀→刂, 邑→阝) but also weak-position curving on the left, and it should not be possible for a character to contain nothing but weak positions. The same problem arises with characters like 利 and 到, if dotting and diagonalization are also only allowed in weak positions (thanks to Daniel Harbour for pointing this out). The response in Myers (2019a) is to write off such oddities as inevitable in lexical grammars, but a more falsifiable (and thus testable) analysis would posit that idiosyncratic allomorphs, being lexically specified rather than derived like regular reduction and curving, are allowed to appear in strong prosodic positions, so 利, 到, 判, and 邦 would all be prosodically [WS]. The rarity of right/bottom idiosyncratic allomorphy would then be explained by the cost of placing a light element of any kind in a strong position, rather than by the cost of extraprosodicity.

Wang (1983) also includes stroke order in his analysis of character grammar, although Myers (2019a, section 3.6.2) argues that it is more analogous to phonetics, since, among other things, it involves only one modality (writing, not reading); we return to stroke order below. Space precludes discussion of other aspects of character grammar, including possible circumfixation or infixation (see Myers 2019a, section 2.3.1.4, and Myers 2019b), syllabification (see Myers 2021a), and dot- and hooking-related patterns (see Myers 2019a, sections 3.4.3 and 3.4.6).

3. Stratal OT and its predictions

Stratal OT, like its predecessors, responds to the gradient variation in morphological and phonological productivity by sharpening the gradience into discrete levels, or strata, ordered from most to least lexicalized. Stratal OT differs from its predecessors in two ways: being more recent, its claims take into account more data than older versions, and being a subtheory of OT, it assumes that while the strata are ordered with respect to each other, each stratum itself is an ordinary OT grammar, that is, a ranking of simultaneously applied universal markedness and faithfulness constraints. Stratal OT also assumes that there are universally three ordered strata, associated respectively with the stem (mostly derivation), the word (including inflection), and the phrase (postlexical) (Kiparsky 2000; Anttila 2006; Bermúdez-Otero 2018).

Stratal OT makes a number of specific predictions about how morphological and phonological systems should work; here I consider six. Although all have been subject to considerable debate, I follow Myers (2019a) in taking my goal as being merely to see if Chinese character patterns can be analyzed with this existing theory, not to argue for or against the theory itself.

The most fundamental prediction, of course, is stratal ordering itself. For example, in English much of the less productive morphology is associated with the stem stratum, such as *-al*, *-ity*, *-ate*, and *-ion*, whereas more productive morphology, including most inflection, is associated with the word level, such as *un-*, *-er*, *-ness*, *-less*, *-ize*, *-s*, and *-ing*. This stratum ordering generally predicts that stem-level affixes should lie within word-level affixes, as in *derivations* ([[[[*derive*]$_{\text{STEM}}$ *ate*]$_{\text{STEM}}$ *ion*]$_{\text{STEM}}$ *s*]$_{\text{WORD}}$). Exceptions are handled by making the link between stratum ordering and affix ordering a bit more indirect. For example, in the notorious word *ungrammaticality*, selectional restrictions require the word-level affix *un-* to apply before the stem-level affix *-ity*. Bermúdez-Otero (2018) deals with this problem by adopting a previous claim that a word-level affix like *un-* defines its own prosodic word, so it can be affixed early while its prosodic behavior arises late; roughly speaking, we have [[*un*[*grammatical*]]*ity*] in morphology but [*un*][*grammaticality*] in prosody. We will see several other examples of such “prosodic escape hatches” in the analyses below.

A second prediction is that different morphological strata are associated with different phonological patterns. In English, stress is assigned to stems, which is why it shifts each time another stem-level suffix is added in *órigin*, *oríginal*, *originálity* but not when word-level suffixes are added in *Américan, Américanize, Américanizing*. Velar softening also applies only with stem-level suffixes, as in *electricity*, but not with word-level suffixes, as in *panicking*. By contrast, German devoicing only applies word-finally (though cf. Rubach 1990) and American English flapping applies phrasally in *get out*.

A third prediction follows from the first two: if the first stratum builds stems and phonology is always associated with strata, then there can be no root-only phonology because there is no root-only stratum. For example, the reason why monomorphemic *órigin* receives normal English word stress is because it is structured as [[*origin* + ∅]$_{\text{STEM}}$]$_{\text{WORD}}$. Thus anything that looks like a morpheme structure constraint (Booij 2011) actually applies in the stem stratum, and in fact the actual domain is likely to be a prosodic constituent that happens to be roughly the size of a morpheme, such as a syllable or foot. Note that the absence of root-only phonology is the inverse of older principles like the strict cycle condition (Kiparsky 1985) or nonderived environment blocking (Kiparsky 1993), which have proven not to hold reliably (Bermúdez-Otero 2013).

A fourth prediction is that all cyclic phonology, the effects of which are preserved into the next round of morphology, applies in the stem stratum (though not all stem-level phonology need be cyclic), before the universally non-cyclic word and phrase strata. Bermúdez-Otero (2013) illustrates this with *imàginátionlessness*, where secondary stress preserves the stress of *imágine* despite main stress shifting with affixation of stem-level *-ate* and *-ion*; the non-cyclic word-level affixes *-less* and *-ness* trigger no further stress shift. Bermúdez-Otero goes on to argue that cyclicity is only possible because because the earlier cycles have been lexicalized, which correctly predicts that it should be associated with lexical idiosyncrasies, as in his minimal pair *ìmpòrtátion* (where the stress of the underlined vowel is preserved from *ìmpórt*) versus *trànsportátion* (where the underlined vowel loses the stress of *trànspórt*).

A fifth prediction follows from the previous one: being lexicalized, cyclic phonology cannot output allophones because lexicalized patterns encode lexical contrasts via phonemic representations. This is just a slight weakening of the older principle of structure preservation (Kiparsky 1982) since it does not apply to non-cyclic phonology, including at the word level (again, see Bermúdez-Otero 2013). For example, stem-level English velar softening replaces the phoneme /k/ with the phoneme /s/, whereas English flapping can create allophones because it is phrasal, and German final devoicing need not fully neutralize voiced consonants with their voiceless counterparts (Port & O'Dell 1985) because it applies at the word level (see Bermúdez-Otero 2010, 2013, for reanalyses of apparent cases of allophonic cyclicity).

The sixth and final prediction to be considered here arises from the OT nature of Stratal OT. Because each stratum is an OT grammar, it is impossible for phonological patterns within a single stratum to have opaque interactions (Kiparsky 2000, 2015), just as in ordinary OT (McCarthy 2007). Instead, their interactions must be "surface-true", with one pattern either "feeding" or "bleeding" the other (by creating or removing its triggering environment, respectively). This in turn implies that all observed instances of opaque interactions must involve patterns in separate strata, which are indeed ordered, just as in pre-OT rule-based theories (Kiparsky 2015; Bermúdez-Otero 2018). For example, the famously opaque (counterfeeding) ordering of Canadian raising (triggered by a voiceless coda) before flapping (which voices the coda) results in a non-surface-true raised diphthong before a voiced coda in *writer* [rʌjɾɚ] (Halle 1962), but this is no problem for Stratal OT because raising is lexical (having lexical idiosyncrasies like *tiger* [tʰʌjgɚ]; Vance 1987) and flapping is postlexical.

4. Testing the predictions in character grammar

While Optimality Theory has proven to be a useful tool in the analysis of writing systems (see e.g. Primus 2004, Song and Wiese 2010, Hamann and Colombo 2017, Evertz 2018, Myers 2019b, Gnanadesikan forthcoming), it does not seem to have been applied to the lexicalization of orthographic patterns. In particular, here we want to know whether the morphological operations and phonological patterns in Chinese characters conform to the above six predictions of Stratal OT. Let us consider them one by one.

4.1 Stratum ordering

Based on the interactions summarized in (2)-(4), the three major morphological operations seem to be ordered relatively unambiguously, with reduplication first, then compounding, and finally affixation.

(2) Reduplication (generally) only applies to individual root morphemes

a. Vertical: 多 昌 炎 圭

b. Horizontal: 比 林 朋 弱 羽 艸

c. Triangular: 品 森 蟲 晶 轟

(3) Compounding only applies to morphemes or reduplicated forms

a. Morphemes: 明 相 尋

b. Reduplicated forms: 區 雙 器 替 琵

(4) Affixation can apply to morphemes and reduplicated, compounded, and affixed forms

a. Morphemes: 住 根 英

b. Reduplicated forms: 錢 琳 臨

c. Compounded forms: 請 想 份

d. Affixed forms: 燙 榴 瞇

The few exceptions to the claim in (2) include historically multimorphemic characters that have been reanalyzed as monomorphemic, as in (5) (cf. English *window*, historically *wind-eye*; see Myers, 2019a, sections 1.2.2.3 and 2.2 for more on ambiguities in synchronic character decomposition). The remaining exceptions are "decorative" characters like those in (6), which are used more for artistic than linguistic reasons, and virtually all of which are extremely rare. We set such exceptions aside.

(5) a. 赫 *Hè* (surname): 赤 *chì* 'red' < 大 'big' + 火 'fire' (compound)

b. 哥 *gē* 'older brother': 可 *kě* 'able' < 口 'mouth' + 丂 *qiǎo* (affixed form)

(6) a. 囍 *xǐ* 'double happiness':

喜 *xǐ* 'happiness' < 壴 'drum' + 口 'mouth' (compound)

b. 䨺 *duì* 'cloudy': 雲 *yún* 'cloud' < 雨 'rain' + 云 *yún* (affixed form)

c. 𣡕 *yàn* (unclear meaning): triangular reduplication of horizontally doubled 林

This apparent ordering of morphological operations, like that in English, correlates with relative productivity: affixation, the final operation, is by far the most productive of the three, responsible for an estimated 80-90% of all modern characters (Myers 2019a, section 1.2.2.1), and there are far more compounds than reduplicated forms. Moreover, affixation is arguably an analog of inflection, since unlike the two other operations it tends to show “agreement” in two-character morphemes like 葡萄 *pútáo* ‘grape’ and 蝴蝶 *húdié* ‘butterfly’ (see Myers 2019a, section 2.3.1.4, and Handel 2019a).

However, character grammar has no phrase level (aside from character phonetics and cursive calligraphy where characters may partly merge) and Stratal OT only offers us two lexical strata: stem and word. Since affixation can apply to the output of any other operation, including itself, no morphological operation ever “finishes” a character, as it must if it applies in the word stratum. Thus there is no word-level morphology in Chinese characters, and all operations must be stem-level. This conclusion is supported by its consistency with another assumption of Stratal OT: recursive affixation means that its associated phonology is cyclic, and cyclicity is only permitted in the stem level.

If all morphological operations are in the same stratum, how then can the apparent ordering be explained? One option is to have reduplication, compounding, and affixation each define its own separate stem stratum, similar to the four stem strata that Jaker and Kiparsky (2020) propose for the Athapaskan language Tetsót’ıné. Alternatively, given that Stratal OT no longer requires affix ordering to strictly follow stratum ordering, we may instead explain interactions among morphological operations via selectional restrictions, as Fabb (1988) argued is needed for English affixation.

4.2 Stratal phonology

In order to test the second prediction, we must examine the associations between morphological operations and phonological patterns in Chinese characters. These are summarized in Table 3, where a blank indicates that the indicated phonological pattern does not apply in the indicated morphological context.

Table 3. Associations between morphology and phonology in Chinese characters

	Axis assimilation	Curving	Prominence	Reduction	Idiosyncratic allomorphy
Morphemes	川, 三	川, 月	三, 川, 由		
Reduplication		辡, 艸	林, 昌	玨, 林, 棗	
Compounding		羧 [a]	尖	坎, 相, 電	人 in 件
Affixation		辣, 羚	奇, 帖	場, 根, 雲	火 in 照

[a] *suō* ‘carboxyl’: 羊 (< 氧 *yǎng* ‘oxygen’) + 夋 (< 酸 *suān* ‘acid’)

As noted earlier, the most robust patterns are prominence and reduction. The first applies in all morphological contexts, including in base morphemes, while the latter only applies across morphemes, regardless of morphological operation. Idiosyncratic allomorphy frequently applies in affixation, in all positions, but never in monomorphemic characters or in reduplication (for example, 水 is replaced with 氵 in the affixed form 清 but not in the reduplicated form 沝). Idiosyncratic allomorphy is also attested in compounding, though mostly restricted to the left position, as noted earlier.

The other patterns in the table require a bit more discussion. The apparent restriction of axis assimilation to individual morphemes raises theoretical problems that will be addressed in the next section. Curving seems to behave as if it is two separate patterns (and this is how Myers 2019a analyzes it), since at the left edge of a morpheme it is obligatory in thin components and quite common elsewhere as well, whereas at the left edge of a character it is restricted to just a handful of morphemes (辛, 羊, 丰, 刂, 半, 屮, 丿). This difference in lexical restrictiveness cannot be explained by reference to morphological domain, since the stem stratum should be more lexicalized than the word stratum, the reverse of what we see here.

However, as often happens in lexical phonology, prosody comes to the rescue. Namely, we can posit a single curving pattern that applies in any prosodically weak position to any target morpheme that is lexically marked to allow it. Regarding the prosodic aspect of this analysis, note that the curving in 厂 *ān* 'cliff' shows that it has a weak-strong [WS] prosodic structure along the horizontal axis, which is preserved in the somewhat opaque compound 原 *yuán* 'source' (cf. 泉 *quán* 'spring'), and when this undergoes left-edge affixation of 羊 'sheep' in 羱 *yuán* 'ibex', the prosodic structure becomes $[W_W[WS]_S]$, allowing curving to apply to 羊 as well. Regarding the lexical restrictions on character-level curving, morphemes like 羊 must be marked to allow curving, rather than marking all non-curving morphemes as exceptions, because the former are far outnumbered by the latter; this is akin to certain phonological patterns in spoken languages being restricted to certain lexical classes (parts of speech or etymological classes, like Latinate morphemes in English or native morphemes in Japanese). Despite the lexicalized nature of character-level curving, however, it must be distinct from idiosyncratic allomorphy because it applies in reduplication. It also acts as if it applies "after" idiosyncratic allomorphy, as in 班, where the central form derives via curving from 刂, which in turn derives synchronically from 刀 via idiosyncratic allomorphy.

4.3 A root stratum?

As we just saw, axis assimilation only applies within morphemes. This seems to suggest that a root-only stratum is needed, but this should be impossible in Stratal OT.

Fortunately, prosody again allows us to side-step the problem. Prominence and curving show that 彡, 三, and 川 are all single feet, so we should say that the domain of axis assimilation is the foot rather than the root. More precisely, prosody applies at the stem level, which includes roots (monomorphemic forms), but since it is cyclic, it also applies to forms derived in this level. This cyclicity is clearly visible in its effects on prominence, as in 圭 *guī* 'pointed jade', where on the first cycle prominence applies to the bottommost stroke in each root 土, and then in the second cycle (reduplication) the entire lower 土 root receives additional prominence. Nevertheless, like English flapping, which is sensitive to the output of cyclic stress without being itself cyclic, prominence is not cyclic either, since the structure built by cyclic prosody remains visible to all later processes (below we provide an additional argument against treating prominence as cyclic).

For similar reasons, axis assimilation and morpheme-edge curving are not cyclic. The synchronic morphological structure of the compound 形 *xíng* 'shape' is 开 + 彡, but curving and prominence shows that each forms its own foot, so the character as a whole has the prosodic structure shown in (7) (开 shows both left-edge curving and lowest-stroke prominence). Similarly, the hierarchical morphological structure of 羱 analyzed above parallels that of its hierarchical prosodic structure, with both the curved left stroke of 原 and the affix 羊 in weak positions, but at different levels of prosodic embedding. The morphology is cyclic (厂

+ 泉 → 原, then 羊 + 原 → 羱) but since the prosodic structure $[W_W[WS]_S]$ remains visible on the surface, morpheme-level and character-level curving can both apply after all of the morphology is done. Even though neither axis assimilation nor curving is cyclic, however, they will prove to have a subtle difference in their stratum placement, as discussed below.

(7) 形 $\left[\begin{bmatrix}W\\WS\end{bmatrix}_W \begin{bmatrix}W\\S\end{bmatrix}_S\right]$

4.4 Cyclicity and stratum ordering

Stratal OT claims that cyclic phonology can only be associated with the stem stratum, though not all stem-level phonology need be cyclic. Consistent with this, reduplication, compounding, and affixation, which we concluded for independent reasons must be stem-level operations, are all associated with cyclic prosody, as shown by its effects on prominence and curving in all three morphological operations.

Moreover, as we have just argued, axis assimilation and curving are sensitive to surface prosodic structure but are not themselves cyclic. For simplicity, then, we tentatively assign all of them to the non-cyclic word stratum, though we will have to modify this analysis later.

Similarly, reduction may seem to apply cyclically in examples like 樹 *shù* 'tree', which shows not just dotting in its outer affix 木 but also diagonalization of 壴 within its phonetic component 尌 *shù*, but actually only prosody is cyclic (樹 has the hierarchical prosodic structure $[W_W[WS]_S]$). Reduction itself applies in all weak positions in the surface prosody, that is, everywhere except at the right and bottom of an entire character.

Idiosyncratic allomorphy also seems to apply cyclically, as in the examples in (8) (⺾ = semantic affix 艸 'grass', 扌= semantic affix 手 'hand', 刂 = phonetic component 刀 *dāo*; note that 巟 in (8a) is presumably derived from 亡 + 川, but our focus here is on allomorphy).

(8) a. 慌 *huāng* 'flustered': [艸[巟]] → [心[艸[巟]]]
b. 捯 *dáo* 'pull rope': [至[刀]] → [手[至[刀]]]

This time the cyclicity may be genuine, however, since idiosyncratic allomorphy depends directly on recursive morphology and not only on prosody. This is demonstrated by (8b), where 刀 takes its idiosyncratically reduced form 刂 because it is lexically specified to do so and not because it is forced to do so by prosody, since the right position should be strong and thus discourage reduction. The preservation of idiosyncratic allomorphy even after left-edge affixation in 捯 makes it non-surface-true and thus reflects lexicalized cyclicity.

Idiosyncratic allomorphy thus must apply in the stem stratum, which requires us to posit a mechanism to block its application in the stem-level operation of reduplication. If the three morpholological operations apply in a series of ordered stem levels (reduplication, compounding, affixation), we can stipulate that idiosyncratic allomorphy is only active in the latter two, although we must be careful to also stipulate that the reduplication and compounding strata are cyclic, since affixation is recursive and thus permits cyclic phonology, and Stratal OT does not allow non-cyclic levels before cyclic ones (the reduplicated form 圭 shows cyclic prosody, as discussed earlier). If all three operations apply within a single stratum (as we assume here for simplicity), we can still explain why reduplication fails to undergo idiosyncratic allomorphy by following Myers (2019b), namely, we rank the constraints for idiosyncratic allomorphy (IDIOALLO) below the correspondence constraint (IDENT-BR) that requires identity between base and reduplicant (RED), as illustrated by the tableau in (9a). As shown in (9b), the same ranking still allows idiosyncratic allomorphy to apply in affixation. Below we will see an argument in favor of this analysis over the analysis with three stem strata.

(9) a.

水 + RED	IDENT-BR	IDIOALLO
☞ 沝		*
氵水	*	

b.

水 + 青	IDENT-BR	IDIOALLO
水青		*
☞ 清		

4.5 Cyclicity and allophonic representations

The prediction of Stratal OT that cyclic phonology cannot output allophonic representations is also confirmed in characters. As summarized in Table 4 (see also Myers 2019a, section 3.5), virtually all of the patterns we have discussed, whether cyclic or not, use features that are also used in making lexical distinctions.

Table 4. The non-allophonic nature of Chinese character phonology

Pattern	Related lexical contrasts
Axis assimilation	二 *èr* 'two' vs. 六 *liù* 'six'
Curving	角 *jiǎo* 'horn' vs. 甬 *yǒng* 'path'
Prominence	土 *tǔ* 'earth' vs. 士 *shì* 'gentleman'
Diagonalization	孑 *jié* 'remaining' vs. 子 *zǐ* 'child'
Dotting	米 *mǐ* 'uncooked rice' vs. 木 *mù* 'wood'
Shrinking	宀 *mián* (affix for roofed structures) vs. 雨 *yǔ* 'rain'
Stretching	廴 *yǐn* (affix for journeys) vs. 人 *rén* 'person'
Idiosyncratic allomorphy	亻(人) *rén* 'person' (as in 住 *zhù* 'dwell') vs. 彳 *chì* 'footstep' (as in 往 *wǎng* 'toward')

We must make a caveat regarding prominence: lexical contrasts in stroke length or component size are only ever binary, but prominence itself can generate more distinctions, as we saw with 圭. This is another reason to analyze prominence as a non-cyclic word-level pattern, despite its being sensitive to the structure built by cyclic prosody in the stem level. To spell this out more explicitly, since 圭 has the prosodic structure in (10a), prominence makes the topmost stroke in $[W]_W$ very short, and assigns the greatest stroke length to the bottommost prosodic slot $[S]_S$. The lengths of the other strokes depend on the script style, though the stroke in $[W]_S$ is always shorter than that in $[S]_W$. In the typeface in (10b), there is a four-way length contrast, though it is extremely subtle: the strokes increase gradiently in length across slots $[W]_W$, $[W]_S$, $[S]_W$, $[S]_S$. There is an easier-to-see four-way contrast in (10c), but now the stroke in $[W]_S$ is shorter than that in $[W]_W$ due to prominence clash (see Myers 2019a, section 3.4.4, for other examples of this phenomenon). Prominence is thus an allophonic process (the same point holds of English stress, though the distinction between prosody and stress is often elided in the phonological literature).

(10) a. $\begin{bmatrix}\begin{bmatrix}W\\S\end{bmatrix}_W\\\begin{bmatrix}W\\S\end{bmatrix}_S\end{bmatrix}$

b. 圭

c. 圭

Of the patterns we have discussed, only stroke order does not make lexical distinctions at all, but it still must be partly lexicalized because it is partly conventionalized; for instance, students in China, Taiwan, and Japan are taught different stroke orders for 必 (see Myers 2019a, section 3.6.2.2). If we were to follow Wang (1983) and treat stroke order as phonology, Stratal OT would require us to assign it to the word stratum (or even later, in the phrase stratum), where phonology is non-cyclic and not (necessarily) lexically distinctive.

4.6 Phonological opacity

The prediction of Stratal OT that only cross-stratum phonological interactions can be opaque also does well in character phonology, starting with the observation that virtually none of the patterns interact at all. For example, 川 undergoes axis assimilation, prominence, and curving, but none of these patterns feeds, bleeds, or otherwise interacts with any of the others. Moreover, prominence and curving are fed by prosody, and as shown in the analysis of 川 in (11), OT has no trouble handling this transparent interaction either.

(11)

<table>
<tr><th>|||</th><th>PROSODY</th><th>AXISASSIM</th><th>PROMINENCE</th><th>CURVING</th></tr>
<tr><td>☞)||$_{ws}$</td><td></td><td></td><td></td><td></td></tr>
<tr><td>)||$_{sw}$</td><td>*</td><td></td><td></td><td>*</td></tr>
<tr><td>)|/$_{ws}$</td><td></td><td>*</td><td></td><td></td></tr>
<tr><td>)||$_{ws}$</td><td></td><td></td><td>*</td><td></td></tr>
<tr><td>|||$_{ws}$</td><td></td><td></td><td></td><td>*</td></tr>
</table>

Similarly, idiosyncratic allomorphy is transparently bled by reduplicative identity, as we saw in the previous section. It also transparently feeds diagonalization, as shown in the tentative analysis of 把 in (12) (ǂ is supposed to represent 手 with the topmost stroke idiosyncratically missing but no other changes); it feeds curving as well, as we saw earlier with 班.

(12)

手 + 巴	IdioAllo	Diagonal
☞ 把		
手巴	*	
ǂ巴		*

Nevertheless, there do seem to be opaque interactions as well. Reduplicative identity is not surface-true (counterfed) in the context of character-level curving and reduction (note the not fully identical copies in 艸, 玨, and 林), as if it applies before, and is partly obscured by, these other patterns. It is not that reduplication ignores all small deviations from identity, just those associated with these specific phonological regularities. For example, 玨 *jué* 'two joined pieces of jade' is derived from 玉 *yù* 'jade', which loses the dot idiosyncratically whenever it is bound, including as an affix in 珍 *zhēn* 'treasure'. Idiosyncratic allomorphy is thus actually sometimes permitted in reduplication, which would be impossible in the three-stem-strata analysis, but there are two severe restrictions: reduplicative identity forces the base to appear in the reduced form as well (as in 玉 + RED → 玨), and this means that the reduced form must not reduce so much that it is banned from a strong prosodic position (as is the case for 玉 → 王, but not for 手 → 扌, 水 → 氵, and so on). That is, even though the loss of a dot is not enough to ban 玉/王 from the strong right position, it is still too much to count as "close enough" for reduplicative identity. This means that reduplicative identity tolerates curving and reduction because of opacity, which ordinary OT cannot handle.

While a variety of different OT devices have been proposed for opacity (see review in Baković 2011), Stratal OT uses stratum ordering. Since reduplication is a stem-level process that triggers reduplicative identity, the patterns that interact opaquely with it (curving and reduction) must apply later, at the word level. This analysis is illustrated in the ordered tableaux in (13) that derive 玨, where the output of the stem-level cophonology (subgrammar) in (13a) becomes the input to the word-level cophonology in (13b), each with its own constraint ranking (玨 does not violate Ident-BR in the word stratum because by then it is no longer marked as reduplication).

(13) a. Stem

玉 + RED	IdioAllo	Ident-BR	Ident-IO	Diagonal
☞ 王王			*	*
玉玉	*			*
王玉		*		*
玨		*	*	

b. Word

王王	Diagonal	Ident-IO	IdioAllo	Ident-BR
☞ 玨		*		
王王	*			

A similar conclusion applies to the opaque counterfeeding interaction between axis assimilation and diagonalization, with the former "hidden" by the latter: note that the two horizontal strokes in 土 are not parallel in 地. Thus even though axis assimilation is not cyclic, Stratal OT requires us to place it in the stem stratum, in order for it to interact opaquely with (i.e., apply before) diagonalization, which we know is in the word stratum. This in turn means that we must revise the analysis of 把 as in (14).

(14) a. Stem

手 + 巴	IDIOALLO	AXISASSIM	DIAGONAL
☞ 扌巴			*
手巴	*		*
把		*	

b. Word

扌巴	DIAGONAL	IDIOALLO	AXISASSIM
扌巴	*		
手巴	*	*	
☞ 把			*

A trickier case of apparent opacity is found with stroke order (see Myers 2019a, section 3.6.2.2). The L-shaped component in (15a) is conventionally written last while that in (15b) is written first, since the former is underlyingly L-shaped ("inside first" order, as in 區) while in the latter the L is stretched from a left-position component ("left first" order, as in 招).

(15) a. 建 = 廴 + 聿

b. 起 = 走 + 巳

Wang (1983) has stroke order apply before stretching (i.e., before reduction and prominence), in an opaque (counterfeeding) interaction, as illustrated in the derivations in (16) (cf. Wang 1983, p. 139).

(16)

	建	起
Underlying	廴 + 聿	走 + 巳
Stroke order:		
Inside first	聿, 廴	NA
Left first	NA	走,巳
Stretching	NA	起
Surface	$_2$建$_1$	$_1$起$_2$

Unfortunately, we argued earlier that the prosody that feeds stretching is cyclic and thus must apply in the stem stratum, while stroke order, being non-cyclic lexicalized phonetics, belongs in a later stratum (word or phrase). Stratal OT is thus confronted here not only with opacity but a rule-ordering paradox as well.

One way to "save" Stratal OT here is to exploit prosodic structure yet again. As Myers (2019a, section 3.3.1.2) realized, the hybrid nature of stretching (reduction on the left and prominence on the lower right) requires special prosodic treatment, but the only formalization given there, reproduced in (17), does not clarify how the various parts relate to each other, nor how the underlying versus derived L forms yield different prosodic structures.

(17) 起 $\begin{bmatrix} W & \begin{Bmatrix} W \\ S \end{Bmatrix} \end{bmatrix}$

The formalizations in (18) attempt to rectify these weaknesses, treating the underlying L in (18a) as essentially horizontal and the yet-to-be-stretched component in (18b) as essentially vertical. In both cases, the second component concatenates in a way that preserves binarity along both axes (i.e., at the top in (18a) but on the right in (18b)). No further patterns apply in (18a), but in (18b) the lower diagonal stroke in the left component is required to undergo stretching in this prosodic context. Prosody thus feeds not just reduction and prominence but also stroke order, which runs top down and left to right in both cases, but following prosodic structure rather than morphemic structure.

(18) a. 廴 $[W \quad S]$ + 聿 $[S]$ → 建 $\begin{bmatrix} S_W \\ [W \quad S]_S \end{bmatrix}$

b. 走 $\begin{bmatrix} W \\ S \end{bmatrix}$ + 巳 $[S]$ → 起 $\begin{bmatrix} \begin{bmatrix} W \\ S \end{bmatrix}_W & S_s \end{bmatrix}$

To summarize, then, the lexical morphology and phonology of Chinese character form has the Stratal OT architecture shown in Figure 1.

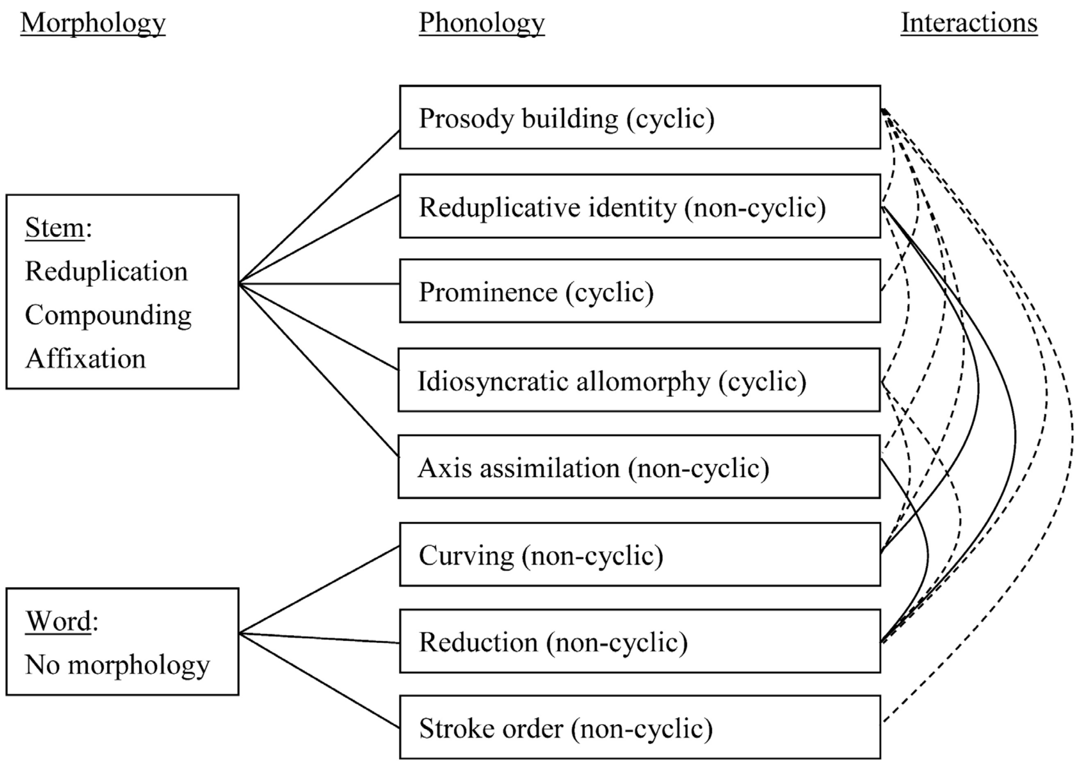

Figure 1. The architecture of morphology and phonology in Chinese character form. Dashed and solid curves indicate transparent and opaque interactions, respectively. Reduction includes diagonalization, dotting, and shrinking; stretching is reduplication plus prominence.

5. Concluding thoughts on speaking, signing, and writing

Not only do Chinese characters seem to have analogs to morphology and phonology, but these seem to interact in the ways predicted for them by Stratal OT. As summarized in Table 5, however, the analogs are not perfect.

Table 5. Morphology and phonology in Chinese characters and spoken languages

Similarities	Differences
Morphology distinct from phonology	Non-recursive compounding
Reduplication, compounding, affixation	No word-level morphology
Non-recursive reduplication	Recursive inflection
Prosody vs. segmental phonology	
Stem vs. word strata	
No root stratum	
Cyclic before non-cyclic phonology	
Dependence of cyclicity on lexicalization	
Opacity only across strata	

That differences exist should not be surprising. Even in spoken languages there is considerable variation across lexical grammars (as noted above, Jaker & Kiparsky 2020 posit four stem strata for Tetsót’ıné). In sign languages, van der Hulst & van der Kooij (2021) argue that there is no true lexical phonology at all; in their own terms, all sign phonology is “utterance phonology” rather than “grammatical phonology”. Their explanation is that the iconicity of sign languages would become obscured if words accrued purely formal allomorphy, but another oft-noted reason for sign grammar being less ad-hoc is that sign languages are "young" (e.g. Aronoff et al. 2005). That is, the cross-generational transmission of sign languages is indirect, since like creoles, sign languages are not usually learned from native-signing parents.

By contrast, character grammar is transferred across generations with great fidelity, simply because the physical forms (e.g. ink on paper) themselves last for generations. At the same time, Chinese characters are more iconic than speech, though this iconicity is far more limited than in sign languages (see Myers 2019a, section 5.2.1.1). It also merely complements rather than supplants grammar; the positions of the components in the compounds 涉 *shè* 'wade' and 泉 *quán* 'spring' may be iconic (氵 'water' next to 步 'step', 白 'white' spring mouth over 水 'water'), but the fact that 水 shows idiosyncratic allomorphy in 涉 but not in 泉 is because of prosody (weak left position vs. strong bottom position).

Chinese script's unique mix of residual iconicity and historical conservativism seems to explain all of the differences in Table 5. Iconicity means compounding cannot be recursive (cf. English compounds like [[[*book*] *store*] *owner*]) because character compounds are headless conglomerates indicating a single meaning (e.g. 盥 'wash' = hands + water + basin, with no single morpheme dominant). There is no word-level morphology because, as noted earlier, affixation is always recursive, which in turn results from the fact that character affixes, though inflection-like in sometimes showing agreement, treat the characters they incorporate as lexicalized wholes. This differs from most spoken and signed languages, where embedded inflectional affixes remain active and thus generally block any others (recursive inflection does exist in spoken languages but it is relatively rare; Arista 2009).

It is such differences in modality that make the many formal similarities among speaking, signing, and writing so striking, as if Chinese character grammar reveals something deep about the nature of human language and information processing systems more generally. We leave further exploration of these issues to the interested reader.

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漢語字體結構模式之間的相互作用

摘要

在我們先前的研究中，論證了漢字的字形受到類似口語及手語構詞及音韻的形式詞彙語法所管束。漢字構詞的運作機制包含重複可被詮釋的基本部件(如：語素）、語義複合和語義部首詞的綴化。漢字的音韻 （如同手語以靜音形式呈現）則由筆畫和部件組成無法被解釋的模式，包含同位語素變體特異化、重複的個體、軸線同化、筆劃對角線化、底部和右側顯著、左側筆劃彎曲；所有上述的規則都受到漢字韻律的影響（沿著橫軸、縱軸的非對稱二元性強弱結構）。在本文中，我們首次嚴謹地探究漢字構詞與音韻相互作用的情形，我們採用階層優選理論（Stratal Optimality Theory）的形式架構，而該理論假定詞幹層統一地排序在詞彙層之前，且每個階層都有各自的 OT 語法。我們使用漢字測試此架構的六個假設，其中包含只有當音韻模式屬於與不同構詞層時，不透明的交互作用才有可能發生，而這些假設出乎意料地符合漢字的結構模式。我們還發現，韻律在解釋如同筆劃順序變化這類困難的案例時，和在口語和手語詞彙分析中一樣扮演關鍵的角色。階層優選理論使我們能比傳統文獻更精確地描述漢字結構，而在這些描述中也包含了書寫與言談和手語共享深層認知機制的新證據。

關鍵字: 漢字、語法理論、音韻學、構詞學、階層優選理論