PART II

The role of frequency in morphological complexity, morphological change and language acquisition

Perspectives on morphological complexity*

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This paper discusses the notion of morphological complexity and differentiates language external complexity (E-complexity) from language internal complexity (I-complexity). While E-complexity is measurable on the basis of the statistical occurrences of affixes and their combinations with roots, I-complexity can be measured on the basis of the number of operations applying in the derivation of morphological forms. The author compares results from studies classifying languages based on their E-complexity to results from studies showing similarities between languages with respect to I-complexity. The comparison reveals that languages with different E-complexity may have similar I-complexity. The author revisits results from psycholinguistic and parsing experiments and discusses how the two sorts of complexity can be reduced. Finally, the role of I- and E-complexity for the understanding of the relation between the language faculty and the external systems is considered.

1. Internal and external complexity

Certain languages are considered to be more complex than others. For example, Latin, a language with rich morphology, is considered more complex than languages with poor morphology, such as Vietnamese.[1] Morphological systems differ in complexity, on the basis of the number of overt affixes and their

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1. There are of course diverse aspects of complexity differentiating languages. In some respect, Vietnamese is more complex than Latin, because Vietnamese morphophonology includes a tone system, whereas this is not the case for Latin. See McWhorter (2001) for a metric for measuring the overall complexity of languages on the basis of overt signaling of phonetic, morphological, syntactic and semantic distinctions. McWhorter's metric can be used when comparing two languages at a time, one of the languages being more complex than the other with respect to each criterion of the metric. It is unclear how this metric could be used to compare the complexity of whole grammars from a typological perspective.

possible combinations with roots. In addition to the complexity of morphological systems, complexity also stems from the derivation of morphological forms. This kind of complexity does not depend on morphological richness but is rather a reflex of the computation of the mind/brain and the structural properties of the derived representations. For example, certain expressions tend to be hard and, in some cases, impossible to process, e.g. word internal multiple center-embedded structures. This fact holds cross-linguistically, and is independent of the richness of morphological systems.

I will refer to the complexity brought about by the external/extensional properties of languages, such as the surface properties of morphological forms, or string-sets, as they occur in paradigms, repertoires, and corpora, by coining the shorthand 'E-complexity'. I will refer to the complexity of morphological forms, or structured-sets, brought about by the operations of the language faculty, by coining the term internal/intensional complexity, 'I-complexity' for short. Both kinds of complexity can be described, measured and quantified.[2] I will refer to this distinction as 'the split complexity hypothesis', and define it simply as follows:

(1) The Split Complexity Hypothesis
Morphological complexity splits into Internal and External complexity.

Generative grammar and statistics/information theory are worth taking into consideration here: in fact, they present different, albeit complementary, approaches to complexity and its measurement in highly articulated systems, such as natural languages, computer programs and biological systems. E-complexity is measurable with statistical and information theoretic methods applied to overt morphological material, such as affixes, and their combination with roots in databases and corpora. I-complexity is measurable in terms of the number of operations generating morphological structures, which may not necessarily be spelled out by overt morphological material.

The proposed distinction between I- and E-complexity is orthogonal to that between inter- and intra-language complexity. Theoretically, it would be possible to access typological as well as intra-language I- and E-complexity, and to provide a typological classification of languages based on I-complexity, as has been done for E-complexity. However, this falls outside the scope of this paper. I will consider the complexity brought about by different sorts of morphological structures in two languages whose morphological systems differ in E-complexity. In doing so, I aim to show that E-complexity differs from I-complexity.

2. Even though the proposed distinction equally covers syntactic complexity, in this paper I will limit the discussion to morphological complexity.

The Split Complexity Hypothesis opens a new space of inquiry as it raises questions on how I-complexity connects with E-complexity, how I- and E-complexity relate to morphological processing and to the acquisition of morphology. Even though I will consider ways of approaching them, the scope of these questions exceeds the limits of this paper, whose purpose is to show that I- and E-complexity are different dimensions of morphological complexity.

In what follows, I will contrast two perspectives on morphological complexity: the statistical information-theoretic approach of Bane (2008), which targets cross-linguistic E-complexity, to the I-complexity approach, which relates morphological complexity to the length of a form's derivation and the number of applications of morphological operations, in the generative model of morphology of Di Sciullo (2005a). I compare Bane's (2008) results on E-complexity to the results of psycholinguistic experiments reported in Tsapkini et al. (2004) and in Di Sciullo & Tomioka (in press) in order to show that languages typologically different with respect to E-complexity may nonetheless have similar internal I-complexity with respect to specific morphological forms. Human processing of I-complexity, as indexed by reaction times, is compared to machine processing of morphological complexity, as indexed by the number of actions performed by a parser to parse complex morphological structures, as reported in Di Sciullo & Fong (2005). I raise the question of how I- and E-complexity can be reduced. Finally, I discuss the role of the Split Complexity Hypothesis for the understanding of the interfaces between the language faculty and the external systems.

I will start with a short discussion on recent works on morphological complexity based on statistical/information-theoretic notions, in order to relate them to the proposed I/E distinction. As I focus on morphological complexity brought about by regular operations, I will not discuss the notion of morphological complexity that has been equated to irregularities, or unexpected forms, in morphological paradigms. This latter perspective attempts to account for irregular forms like irregular plurals observed in English, for instance *ox/oxen*, *goose/geese*, and *sheep/sheep*, where the difference between the singular and the plural is signaled in a way that departs from the regular pattern. Allomorphic variants are also accounted for by the irregularity-driven approach to morphological complexity. For example, the *-s* in *dogs* is not pronounced the same way as the *-s* in *cats*; and, in a plural like *dishes*, an 'extra' vowel appears before the *-s*. This approach to morphological complexity also covers cases where there are mismatches between the form and the meaning of morphological expressions, either because the semantics is not (entirely) compositional, or because there is a mismatch between form and interpretation, as is the case of *cranberry* and *stepsister*. The lack of one-to-one correspondence between form and meaning in derivational morphology as well as in compounding is a kind of complexity that may fall into the irregularity-based perspective on morphological complexity. See Corbett & Baerman (2010) for a recent discussion on irregularities in morphological paradigms.

2. Information theory and complexity

Information Theory (Shannon 1948) involves quantification of information in terms of bits (binary digits: 0, 1), and includes operations to compress, store and communicate data. Entropy is a key measure of information, which is expressed by the average number of bits needed for storage or communication. Information theory also involves mathematical operations calculating the frequency and the probability distribution of data. For example, Zipf's Law (Zipf 1949) predicts the relative frequency of words in a corpus. According to Zipf's Law, the frequency of any word in a text is inversely proportional to its rank in a frequency table. Thus, the most frequent word will occur approximately twice as often as the second most frequent word, three times as often as the third most frequent word, etc. Statistical analyses are used to measure complexity, including the complexity of morphological systems.

Algorithmic information theory is concerned with the complexity of strings of data. For example, in the theoretical approach of Kolmogorov (1965), complexity of a string is obtained by identifying the length of the shortest binary program that can output that string. In algorithmic information theory, the Kolmogorov complexity of an object, such as a piece of text, is a measure of the computational resources needed to specify that object. What Kolmogorov complexity (Solomonoff 1964; Kolmogorov 1965; Chaitin 1987) aims to formalize is that one object is more complex than another insofar as it takes longer to describe it as a string in some description language. For example, the strings *abababababababababab* and *anwitmlahwrojnsbwube* both consist of 20 characters. While the first string can be described simply as '*ab* 10 times', the second one has no shorter description than itself. Thus, the first string is less complex than the second.

Statistic/information theoretic notions have been used in several works on morphological complexity, including Juola (1998, 2007), Moscoso del Prado Martín et al. (2004), Dahl (2004), McWhorter (2001), Shosted (2006), Bane (2008), and Nichols (2009). It is useful to consider these works from the perspective of the proposed I-/E-complexity distinction. In this respect, the following questions come to mind. What kind of complexity are they targeting? How do they contribute to our understanding of morphological complexity? And what questions do they raise?

Corpus-based analyses of morphological complexity, including Juola (1998), Bane (2008), Nichols (2009), and McWhorter (2001) for example, use information-theoretic methods to measure the morphological complexity of diverse languages and consider mainly E-complexity. Even though these works adopt different methodologies, their results converge, for example in both Juola (1998) and Nichols (2009) French is attested to be more morphologically complex than English. Dahl (2004) mainly addresses linguistic complexity from a language change perspective, and relies on information-theoretic notions to determine the complexity of what he calls "mature" constructions. Dahl's works rely on Kolgomorov's information-theoretic measure of complexity of an expression as the length of its shortest description. Dahl's perspective on linguistic complexity is congenial to the notion of I-complexity introduced in this paper, in the sense that it is brought about by the evolution of language. Complexity is not a measure of difficulty but rather an absolute and objective property of the system.

Juola (2007: 89) focuses not only on the mathematical aspects of complexity, but on the psychological ones as well: "Any claim about 'complexity' is inherently about process, including an implicit description of the underlying cognitive machinery. By comparing different measures, one may better understand human language processing and similarly, understanding psycholinguistics may drive better measures." He suggests relating the information theoretic approach to morphological complexity to the theories of psycholinguistic processing of lexical properties. The question whether the lexicon and lexical properties fall into I-complexity, or whether lexical properties are acquired on the basis of experience, and thus fall into E-complexity, is an open question. According to Di Sciullo & Williams (1987), Chomsky (1970, 1995, forthcoming), and Di Sciullo (2005a, 2009), the lexicon is a list of items whose properties must be learned, as some of these properties cannot be derived by the operations of the grammar. It is not clear that the processing of lexical properties, defined in terms of frequency of affixes and their interchangeability within words in a corpus falls within I-complexity, which is the complexity brought about by the internal computations of the mind in the derivation/processing of word structures.

Likewise, the works of Moscoso Del Prado Martín et al. (2004) and Milin et al. (2009) describe a probabilistic measure of the informational complexity of a word. Complexity is a function of the amount of information contained in a word and the amount of information brought about by its morphological paradigm. To the extent that these studies rely on overt material, including written words, and lists of words in a lexical repertory, such as CELEX, they provide a measure of E-complexity of affixes, defined in terms of number of binary choices required to access them within frequency dependent hierarchies of affixes. It is also unclear whether these studies target I-complexity, assuming that the lexicon is not a generative component of the language faculty. The kind of complexity targeted is representational, and not derivational, in the sense defined here, i.e. in terms of generative operations applying in the derivation/processing of word-structure. As mentioned previously, these operations may in some cases not be associated to overt material, and thus fall within the range of phenomena accessible to I-complexity. Furthermore, it remains to be seen whether lexical look-ups should be dealt with on a par with the computational structure building operations of the language faculty in the narrow sense (FLN), defined by Hauser et al. (2002). In Section 3, I will illustrate the statistical/information theoretic perspective on morphological complexity with Bane's (2008) cross-linguistic ranking. This study undoubtedly falls into E-complexity. In Section 4, I will consider the generative grammar perspective on morphological complexity, and illustrate this perspective with studies that fall into I-complexity.

3. Measuring E-complexity

Bane (2008) argues for an information theoretic approach to linguistic complexity and offers preliminary results for a method for using the mathematical notion of Kolmogorov's complexity together with an automatic lemmatizer, Linguistica (Goldsmith 2001, 2006), to construct a numerical metric of morphological complexity. Linguistica is an automatic lemmatizer that attempts to construct the smallest possible model of the data, which is at the same time able to predict the data as efficiently as possible. Linguistica reads in a corpus of text in the target language and iteratively applies a series of heuristics to find the simplest model (a lexicon) that best describes the corpus. Linguistica applies to a text and induces a morphological lexicon of stems, prefixes, suffixes, and their signatures describing their possible combinations. The example in (2), from Bane (2008), provides a sample of the morphological lexicon for the French stems *accompli-* 'accomplish', *académi-* 'academy' and *académicien-* 'academic'. The suffixal signature is the set of suffixes the stems combine with. The suffixal signature for the stem *accompli-* includes the null suffix -Ø for the singular form of the adjective, *accompli*, and the suffix *-e* for the feminine, *accomplie*, the suffix *-t* for the third person singular verbal from *accomplit*, the suffix *-r* for the infinitival form, *accomplir*, and so on. The suffixal signature for the stem *académi-* includes the nominal suffix *-cien*, *académicien* 'academic', the suffix *-e* for the noun *académie* 'academy', the suffix *-es* for the plural form *académies*, and the suffix *-que* for the adjectival form, *académique*. The suffixal signature for *académicien-* includes the null suffix -Ø for the singular form, *académicien*, and the *-s* suffix for the plural form, *académiciens*.[3]

3. As mentioned by an anonymous reviewer, the set of French suffixal signatures is based on the orthography, when phonologically the set will be less (e.g. *accompli* + *t* and *accompli* +Ø

(2) Stem Suffixal Signature
a. *accompli* *Ø.e.t.r.s.ssent.ssez*
b. *académi* *cien.e.es.que*
c. *académicien* *Ø.s*

For each stem, affix, and signature, a description length is calculated and tracked. The simplest model in this case is that with the smallest total description length over all stems, affixes, and signatures. These description lengths are approximations, or indices, of complexity. It follows that a lexicon's total description length is an approximation of its complexity.

Bane (2008) proposes that the morphological complexity of different languages can be measured as the proportion of their lexicon's total description length that comprises the description lengths (DL) of affixes and signatures. That is, if DL(x) is the description length of x, then:

(3)
$$\text{Morphological complexity} = \frac{\mathrm{DL}(\text{affixes}) + \mathrm{DL}(\text{signatures})}{\mathrm{DL}(\text{affixes}) + \mathrm{DL}(\text{signatures}) + \mathrm{DL}(\text{stems})}$$

(Bane 2008: 73 (4))

A corpus-based analysis of the translation of the Bible in 20 languages using Linguistica provides the following ranking of the surveyed languages with respect to their percentage of morphological complexity (Table 1).

Table 1. Computed values of the proposed ratio metric (3) for all 20 languages surveyed (from Bane 2008: 71)

Language	Metric	Language	Metric
Latin	35.51%	English	16.88%
Hungarian	33.98%	Maori	13.62%
Italian	28.34%	Papiementu	10.16%
Spanish	27.50%	Nigerian Pidgin	9.80%
Icelandic	26.54%	Tok Pisin	8.93%
French	23.05%	Bislama	5.38%
Danish	22.86%	Kituba	3.40%
Swedish	21.85%	Solomon Pijin	2.91%
German	20.40%	Haitian Creole	2.58%
Dutch	19.58%	Vietnamese	0.05%

would be the same in phonological terms). This is important because it means that the calculation of morphological complexity can be influenced by a language's orthographic complexity.

Thus, cross-linguistic morphological complexity can be measured using statistical methods. In the statistical approach, a criterion of morphological complexity is the actual number of affixes available in a given language and the number of possible combinations of these affixes with respect to roots/stems.[4]

The computed values in Table 1 are based on the overt morphological richness of the languages surveyed. The results are not based on the covert complexity of morphological derivations. As mentioned previously, comparing a typological ordering of the languages with respect to E-complexity, such as the one presented in Table 1, to a typological ordering of languages with respect to the I-complexity of morphological forms is not the purpose of this paper. This paper aims to substantiate the Split Complexity hypothesis by showing that I- and E-complexity do not coincide. I will provide evidence that languages whose morphological systems differ in E-complexity may have the same I-complexity with respect to the derivation/processing of morphological forms.

I-complexity and E-complexity are different dimensions of morphological complexity. While I-complexity is brought about by the mental states associated to the computation of the mind/brain, E-complexity is brought about by linguistic behavior. Statistically based typological ordering of languages based on behavior may fail to capture meaningful cognitive states. Meaningful cognitive states do not necessarily map onto observable behavior. Statistics provides a perspective on a specific type of complexity, E-complexity, whereas generative grammar provides a different perspective, that of I-complexity.

4. Generative grammar and complexity

The discussion on complexity in generative grammar goes back to Chomsky's (1956) hierarchy of formal grammars, according to which grammars are ranked according to their generative capacity to generate languages of increasing complexity. For example, the complexity of context-free grammars is higher than the complexity of finite state grammars. The latter include abstract categories in addition to terminal elements, and derive hierarchical structures. They allow for recursive (both direct and indirect) and center-embedded constituent structures. Several works from the 70s and the 80s discussed the generative capacity required to describe the complexity of the English vocabulary and the morphological complexity of other vocabularies, including for instance the vocabulary

4. It is worth noting that written language like spoken language is part of linguistic behavior, and thus their complexity fall into what I call E-complexity.

of Bambara (Culy 1985). Several works addressed the question of how recursive direct, indirect and center-embedded affixation is derived, and whether the generative power of finite-state or context-free grammars is required to derive the complexity brought about by overt morphological structures. It has been argued that the generation of unbounded center-embedding word structures requires the power of structure building context-free grammars (Bar-Hillel & Shamir 1960; Langendoen 1981; Carden 1983; Shieber 1985).[5]

Consider the examples in (4)–(6), which illustrate word-internal recursion. Recursion, as observed in expressions such as (4), has been discussed in several works, including Halle (1970), Di Sciullo (2011), and Lasnik (2011).[6] Such cases are interesting, as they require that the generative capacity of the grammar be higher than finite state. While a finite state grammar allows local recursion of a given item, as in *an old old old book*, its descriptive capacity cannot generate languages whose expressions consist of a number of *a* elements followed by an equal number of *b* elements plus one: *abb, aabbb, aaabbbb, aaaabbbbb*, and so on. A finite state grammar cannot keep track of the number of *a's* in order to make the number of *b's* greater by one. Thus expressions such as *anti-anti-missile-missile-missile*, *anti-anti-anti-missile-missile-missile-missile*, and so on, can only be generated by grammars with greater generative capacity than finite state grammars.

The examples in (5) are discussed in Bar-Hillel & Shamir (1960), Langendoen (1981), Carden (1983), Shieber (1985), as cases of center embedding within word structure. For example with [$_A$un[stabil$_A$ iz$_V$]able$_A$], a deadjectival verb structure is center embedded in adjectival projections.[7] The examples in (6) are cases of indirect recursion at the right periphery of word structure. That is, the nominal affix *-ness* is embedded in an adjectival affix *-less* recursively, i.e. mark ed$_A$] ness$_N$] less$_A$].

5. The fact that multiple center embedding is difficult to parse has been attributed to a parsing constraint in Chomsky & Miller (1963), according to which sentence processing cannot be interrupted more than once. Compare (i) and (ii).

(i) The bug [$_{CP}$ the programmer found] is not fixed.
(ii) #The bug [$_{CP}$ the programmer [$_{CP}$ the boss knew] found] is not fixed.

6. See also Pullum & Tiede (2010) on the trade-off in terms of the descriptive power of a metalanguage and the set of features required in the derivations.

7. The acceptability of recursive structure under the word-level decreases rapidly, as indicated with # and ## in (4)–(6). It might be the case that the parsing limitations discussed in Chomsky & Miller (1963) for the processing of multiple center-embedded syntactic structures is also at play in the processing of word structure.Word processing, like sentence processing, cannot be interrupted more than once.

(4) *anti missile missile, #anti anti missile missile missile, ##anti anti anti missile missile missile missile, …*

(5) *unstabilizable, #undestabilizableizable, ##undeundestabilizableizable, …*

(6) *markedness, #markednessless, ##markednesslessness, …*

Generative grammar is concerned with the complexity of grammars and the operations defining them. Fodor et al.'s (1974) evaluation metric is based on the number of applications of operations, or the length of the derivations. Their treatment of complexity of a sentence is obtained by identifying the length of the derivation, *viz.*, the number of operation applications needed to output that sentence. This perspective focuses on the complexity brought about by the recursive application of the operations of the grammar.[8]

In current developments in generative grammar, the Minimalist framework and the Biolinguistics program, the number of possible operations of the grammar is reduced to a bare minimum. In fact, there is just one: the binary recursive operation Merge. Merge is the core operation of FLN recursively deriving the infinite set of linguistic expressions. This approach to the properties of FLN has both methodological and explanatory advantages over theories that include combinatorial operations in addition to other operations for the generation of linguistic expressions. It satisfies scientific desiderata of simplicity and it provides a way to address the question of the emergence and evolution of language on the basis of a simple and clear hypothesis. It is also harmonious with Fodor et al.'s theory of complexity.

In this perspective, morphological complexity can be measured in terms of the number of applications of the operation deriving morphological expressions, and a Kolmogorovian definition of I-complexity can be constructed to calculate the complexity of morphological derivations. The question that arises is whether the internal computation of the mind/brain, mainly the recursive application of the operation combining morphological elements, gives rise to complexity notwithstanding the absence, in certain cases, of overt material signaling the application of the operation. In this perspective, morphological complexity can be substance free, in the sense that there is no overt material on which to rely at the sensorimotor (SM) interface to evaluate the morphological complexity

8. Kolmogorov complexity is a general notion, as an anonymous reviewer rightfully pointed out. It is possible to apply its principles to construct definitions of both I- and E-complexity. In the external case, Kolmogorov complexity is about the complexity of surface representations or string-sets, and in the internal case, it is about the complexity of derivations and underlying representations. In both cases, the object of interest can be identified as more complex if its minimal, complete description in some agreed-upon description language is longer.

of the surface representations, or string-sets. The results of the psycholinguistic experiments discussed in Section 4.2 indicate that this is the case. Before discussing these results, however, I will clarify the notion of morphological derivations in order to illustrate how morphological expressions, i.e. the structural descriptions of words, are derived by the application of a number of morphological operations.

4.1 Measuring I-complexity

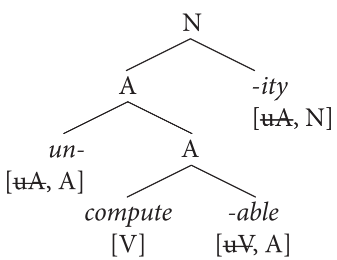
4.1.1 *Derivations*

According to Di Sciullo (2005a), morphological derivations are brought about by the iterative/recursive application of morphological merger. Assuming that affixes and roots have valued and unvalued categorical features, given the numeration in (7), the recursive application of morphological merger yields the derivation in (8), which can be represented by the tree in (9).

(7) Numeration: {compute: [V], -able: [A, uV], un-: [A, uA], - ity: [N, uA]}

(8) 1. Merge ([V], [~~uV~~, A])
2. Merge ([A], [~~uA~~, A])
3. Merge ([A], [~~uA~~, N])

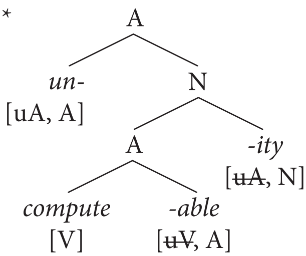
(9)



In successful derivations, the proper inclusion relation determines the order in which items of the Numeration are combined. Thus, in the derivation of *uncomputability*, *un-* can only merge with *compute-able*, as in the derivation in (8). It cannot merge to *compute-able-ity*, as in the derivation in (10), as the uninterpretable features cannot be valued at the third step of the derivation. Namely, the set of features of the affix *un-*, i.e. [uA, A], is not a superset of the set of features of the nominal affix *-ity*, i.e. [N], after the elimination of its unvalued A feature, i.e. [~~uA~~], as depicted in (11). The morphological derivation crashes as some features it includes remain unvalued and consequently they are uninterpretable by the semantic system.

(10) 1. Merge ([V], [~~uV~~, A])
2. Merge ([A], [~~uA~~, N])
3. *Merge ([uA, A] [N]) (no proper inclusion)

(11) *



In the successful derivations, such as (8), the sets of features of the elements undergoing morphological merger are in a proper subset relation, whereas this is not the case in the unsuccessful derivation in (10). Di Sciullo (2005a) proposed that set inclusion is part of the morphological derivation and it ensures that linguistic expressions are legible by the external systems, the conceptual-intentional (CI) and the sensorimotor (SM) systems. The set inclusion relation contributes to reducing derivational complexity, as it restricts the class of potential derivations.[9]

Assuming that morphological derivations may yield structures where no phonetic features are associated with terminal nodes, as in Di Sciullo (2005a),[10] morphological complexity, understood in terms of the number of applications of morphological merger, may give rise to expressions that are not distinct with respect to the number of affixes and roots, but are distinct with respect to the number of applications of morphological merger. In the following paragraphs, I revisit the results of psycholinguistic experiments on the perception of derived verbs and acceptability of compounds. The stimuli used in these experiments do not differ with respect to the linear properties of their parts. However, they do differ in hierarchical structure, and thus, in the number of applications of morphological merger.

The results of the psycholinguistic experiments reveal that languages that differ with respect to E-complexity are similar with respect to I-complexity. For example, considering the statistical ranking in Table 1, French is associated with a percentage of complexity of 23.05%, and English with a percentage of 16.88%. However, the results of the psycholinguistic experiments reported in Tsapkini et al. (2004) for the processing of complex verbs in French, and the results reported in Di Sciullo & Tomioka (in press) based on the acceptability of novel compounds in English, show that French and English do not differ with respect to I-complexity. In the following

9. This condition also applies in the derivation of phrasal syntax, as shown in Di Sciullo & Isac (2008), and in the derivation of compounds, as discussed in Di Sciullo (2009).

10. The derivation of morphological structure lacking phonetic features in the Asymmetry of Morphology framework (Di Sciullo 2005a) can be viewed as a configurational instantiation of zero-affixation in other frameworks, including Hale & Keyser (1993).

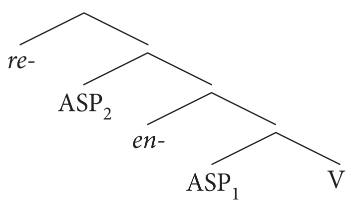
sections I stress the importance of these findings for the theory of morphological complexity. The purpose of these experiments was to test whether configurational asymmetry between internal and external constituents to the verbal projection played a role in processing prefixed verbs and compounds. The first experiment is based on French internally and externally prefixed verbs; whereas in the second, the data is based on novel object-verb and adjunct-verb English compounds.

4.2 Experimental results

4.2.1 *Prefixed verbs*

Tsapkini et al. (2004) report the results of two experiments designed to test whether the analysis proposed in Di Sciullo (1997) on the structural asymmetry between internal/directional prefixes, such as French *en-* and *a-*, and external/sequential prefixes, such as French *re-* and *dé-* in French verbs is reflected in processing differences. In Di Sciullo (1997), an internal prefix is generated within the verbal projection; an external prefix is generated outside of the verbal projection. The configurational asymmetry between internal and external prefixes is preserved in the Asymmetry framework of Di Sciullo (2005a), where directional affixes and sequential affixes compose with verbs at different hierarchical positions. This is the case for French directional affixes, such as *en-* and *a-*, (hereafter ASP$_1$) and sequential affixes, such as *re-* and *dé-* (hereafter ASP$_2$). ASP$_1$ is closer to the internal argument structure of the verbal root than the latter, as depicted in (12).[11]

(12)



The examples below provide empirical evidence supporting the existence of a hierarchical asymmetry between sequential and directional affixes. Assuming that Kayne's (1994) Linear Correspondence Axiom (LCA)[12] applies to word structure, ASP$_2$ affixes are hierarchically higher than ASP$_1$ affixes, since ASP$_2$ affixes must precede ASP$_1$ affixes, (13). If, as Di Sciullo (1997; 2005a) proposed, only ASP$_1$ affixes are part of the Aktionsart domain of the verb, I correctly predict that ASP$_2$

11. See Di Sciullo (2005b) showing that the proposed hierarchical asymmetry extends to Italian, and Di Sciullo & Slabakova (2005) showing that it extends to Bulgarian.

12. According to the LCA, linear order of linguistic constituents is a function of their asymmetrical c-command relations.

affixes can be iterated, unlike ASP_1 affixes, (14).[13] This is further confirmed by the denominal verbs data in (15), where an ASP_1 affix, providing the internal verbal aspect to the projection, must be spelled out if an ASP_2 affix also is.[14] Finally, the difference in structural position between ASP_1 and ASP_2 affixes is further confirmed by the fact that ASP_1 affixes, but not ASP_2 affixes, may give rise to argument structure shift, (16).

(13) a. *Elle a réemporté/*enréporté* LINEAR ORDERING
she has RE.AWAY.brought/*IN.RE.brought
les livres.
the books
'She brought the books away again.'

b. *Elle a réenfermé/*enrefermé le chat dans la cave.*
she has RE.IN.lock/*IN.RE.lock the cat in the cellar.
'She locked in the cat in the cellar again.'

(14) a. *Elle a rerefait/redéfait le puzzle.* ITERATION
she has RE.RE.done/RE.UN.done the puzzle
'She redid the puzzle again./She undid the puzzle again.'

b. **Elle a aa/enemporté/aen/enapporté*
she has TO.TO/AWAY.AWAY brought/TO.AWAY/AWAY.TO brought
les livres.
the books
'She brought the books to to away away.'

(15) a. *Il a réembouteillé/*rebouteillé le vin.* LOCALITY
he has RE.IN.bottled/*RE.bottled the wine
'He rebottled the wine.'

b. *Il a réembarqué/*rebarqué sur le bateau.*
he has RE.IN.bark/*RE.bark on the boat
'He re-embarked on the boat.'

13. Based on the assumption that adjuncts, but not arguments can be iterated. External aspect (ASP_2) can be iterated, as it is an adjunct to the verbal projection. Internal aspect (ASP_1) is part of verbal argument structure projection, and thus cannot be iterated.

14. The denominal verbs *ré-em-bouteill-er* and *ré-em-barqu-er* do not have a verbal base, but a nominal base, *bouteille, barque.* Internal aspect (ASP_1) must be spelled out within the verbal projection before external aspect (ASP_2) is. This is not the case for the prefixed verbs *re-fermer* and *en-fermer*. Other examples illustrating the phenomena include: **rechaîner* vs. *réenchaîner* 'to rechain', **refariner, réenfariner* 'to dust with flour again', vs. *enfermer* 'to lock X up', *refermer* 'to close X again'; *entailler* 'to gash in', *retailler* 'to cut again'.

(16) a. *Il a (re)dormi pendant des heures.* A-STRUCTURE SHIFT
he has (RE)slept for DET hours
'He slept for hours (again).'

b. *Il a (r)endormi Jean immédiatement.*
he has (RE).IN sleep Jean immediately
'He got Jean to fall asleep (again) immediately.'

These facts lead us to conclude that, their string-linear similarity notwithstanding, verbs such as *re-fermer* and *en-fermer* differ with respect to their hierarchical structure.

While controlling for the other factors found to influence the lexical access of prefixed forms, such as semantic transparency and stem and surface frequencies, Tsapkini et al. (2004) investigated the effects of configurational asymmetry in the recognition of prefixed verbs in French. A simple lexical decision paradigm was used to compare prefixed verbs with external and internal prefixes, as specified in Di Sciullo (1997). Two experiments were conducted.[15] In the first experiment, the bivalent prefix *dé-* was tested, and the configurational difference between external and internal properties of the prefix did not elicit differential response latencies. In the second experiment, monovalent prefixes, the external *re-* and the internal *en-* were tested. The verbs with the external prefix elicited longer latencies. Planned comparisons between the base forms of *en-* and *re-* revealed no significant difference [$F = 2.3$, $p = .14$], whereas planned comparisons between the prefixed forms of *en-* and *re-* revealed a significant difference [$F = 6.7$, $p < .017$] indicating that the observed interaction was caused by the different RTs between the prefixed forms. The results of the priming experiments indicate that *re-* prefixed verbs are processed more slowly than *en-* prefixed verbs.

Table 2. Mean Reaction Times (RTs) and Standard Deviations (SDs) for internal and external prefixed and stem forms. Tsapkini et al. (2004)

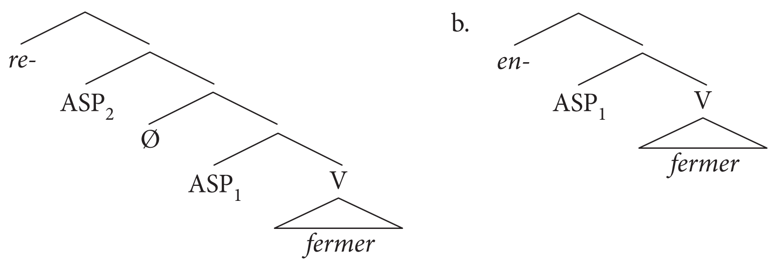
	Mean RTs	SDs
En stem	648	95
Re stem	628	80
En prefixed	724	97
Re prefixed	766	140

Tsapkini et al. (2004) show that this difference could not be accounted for by any difference in stem frequencies or surface frequencies or by any of a number of

15. See Tsapkini et al. (2004) for the details of the design of these experiments.

other distributional factors, e.g. syllable length, affix homonymy, etc. It can only be attributed to the particular configurational properties of the prefixes. The fact that externally prefixed verbs are longer to process than internally prefixed verbs is surprising for theories of lexical access based on the frequency of affixes, since *re-* has a higher frequency than *en-* in French verbs. This is observed in Goldsmith (2001), where in a 100,000-word corpus, only 6 occurrences of *en-* prefixed verbs are attested, as opposed to 18 occurrences of *re-* prefixed verbs and 17 occurrences of *ré-* prefixed verbs. Several studies of word processing focus on whether or not lexical access for complex words is holistic or whether the parts of complex words are processed separately. One interpretation of the results reported in Tsapkini et al. (2004) is that while internal prefixes would be accessed with the verbal base, the external prefixes would not, and thus the processing of *re-* prefixed verbs lead to longer latencies than the processing of *en-* prefixed verbs. From an E-complexity perspective, it is surprising that higher frequency affixes take longer to process than lower frequency affixes. In fact the contrary is predicted. Considering these results form an I-complexity perspective, however, the differences in latencies follow naturally from the complexity brought about by the computational load: the number of applications of morphological merger. Thus, from an I-complexity perspective, Tsapkini et al. (2004) indicate that there is a significant difference in the processing of ASP_1 (e.g. *re-fermer* 'reclose') vs. ASP_2 prefixed verbs (e.g. *en-fermer* 'enclose') that may be attributed to the number of applications of morphological merger.

(17) a. b.



Morphological complexity related to I-language cannot be equated to the number of occurrences of affixes in a corpus. Statistics and probability cannot measure I-complexity, which is a function of the computations of the faculty of language.[16]

While differences in lexical access could be invoked for the interpretation of the results on prefixed verbs, this is not the case for the preliminary results from

16. As pointed out by a reviewer, the statistical significance of Table 2 might not be explained by easier affix chopping in more peripheral affixes as compared to less peripheral affixes or by difference in semantic transparency. It is unclear how such differences could predict the significant difference in reaction times between externally and internally prefixed verbs. In contrast, the differences in reaction times for the configurations at hand follow directly from differences in I-complexity.

the novel compounds experiment that will be discussed in the next section, as novel compounds are not listed in the lexicon. An I-complexity interpretation of the results of the lexical decision experiment for French internal and external prefixed verbs is independently supported by the results on acceptability judgements for English adjunct-verb and object-verb novel compounds.

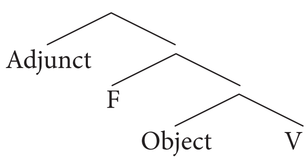
4.2.2 *Compounds*

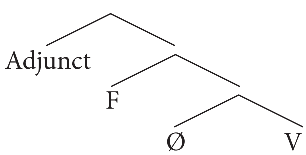
The purpose of the compound experiment was to test whether the configurational asymmetry between object-verb and adjunct-verb compounds has a processing correlate.

The asymmetry between objects and adjuncts has received much attention in works on compound formation (e.g. Baker 1988; Rosen 1989; Rivero 1992; Spencer 1995). A major puzzle concerning compounds is that, even though Head-movement captures the formation of object-verb type compounds (Baker 1988) (see (19)), it cannot account for the existence of adjunct-verb compounds (see (18)). Assuming that the complement occupies a position lower than the adjunct in NV-compounds, as described in the simplified tree in (20), adjunct-verb compounds are more complex than object-verb compounds as they require an additional number of applications of morphological merger.

(18) *the finger-painted portrait*

(19) *the meat-cutting knife*

(20)


(21) a.


b.


In the experiment reported in Di Sciullo & Tomioka (in press), 10 English speakers were shown 60 sentences containing two types of novel compounds – object-verb and adjunct-verb. All the verbs used in the compounds are mono-transitive and the classification of the compound is self-evident from the sentence. When the nominal constituent is the logical object of the verb, the nominal saturates the argument requirement of the verb and hence the compound is an intransitive verb. In contrast, when the nominal constituent is an adjunct, the argument structure requirements of the verb are not satisfied (the predicate is still unsaturated) and the compound is a transitive verb.

Each type of compound appears in three contexts. The compounding is most productive in the control context that corresponds to the participial use. In addition, there are two verbal contexts with different tense/aspect morphology (*-ing* or *-ed*). The object-verb compound is a saturated predicate and hence it appears as a participle with *-ing*, combining with a noun that is interpreted as the subject, as in *the meat-cutting knife*. The adjunct-verb compound is an unsaturated predicate and hence it appears as a passive participle with *-ed*, combining with a noun that is interpreted as the object, as in *the finger-painted portrait*. The data in (22)–(27) constitute a sample of the data used in this experiment.

Object-V

(22) *The dreamer star-counted all night.*
The traveler bird-caught in the back yard.

(23) *The biologist was root-collecting in the forest.*
The scientist was cell-counting in the lab.

Adjunct-V

(24) *The valet sand-parked the client's car.*
The pilot desert-landed the small plane.

(25) *The sailor was sea-parking his yacht against the rule.*
The florist was glass-painting the orchid.

Fillers

(26) *The girl turned on the clock-light on the wall.*
The penguin met her pole-sister after the storm.

(27) *The actor bought a wish-dress for the party.*
The editor inserted the sentence as an afterthought.

The results of this experiment show that compound processing is sensitive to hierarchical relations. In this experiment, two sorts of NV compounds were used, differing with respect to their hierarchical relations, as illustrated in (21) above. The acceptability rates of the two sorts of compounds differ as depicted in Table 3 and Figure 1.

Table 3. Acceptability rates for English novel NV compounds where lower scores indicate higher acceptability and higher scores indicate lower acceptability

	Object-Verb	Adjunct-Verb
Past Tense (*-ed*)	3.43	2.74
Progressive (*-ing*)	2.72	3.45

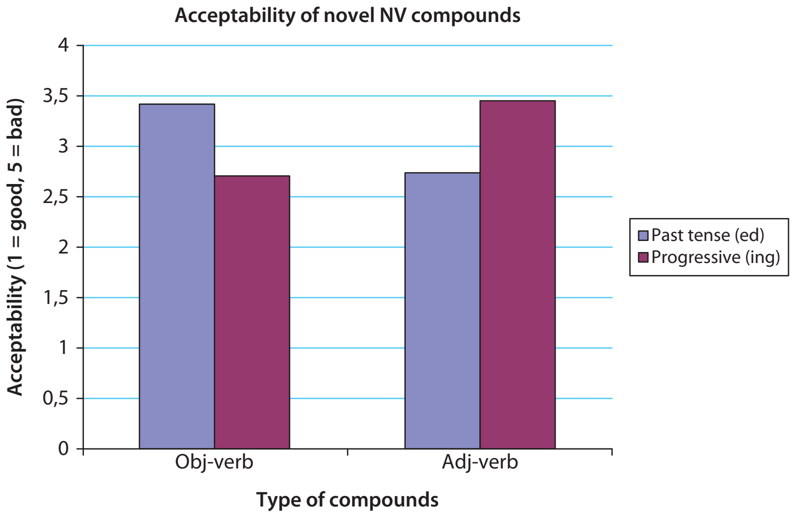


Figure 1. Acceptability results for English novel NV compounds where lower scores indicate higher acceptability and higher scores indicate lower acceptability. Di Sciullo & Tomioka (in press)

The results effectively show that there are differences in the acceptability of novel object-verb vs. adjunct-verb compounds. The acceptability of novel object-verb compounds with *-ed* morphology is lower than the acceptability of adjunct-verbs with the same morphology. Furthermore, the acceptability of object-verb compounds with *-ing* morphology is higher than the acceptability of adjunct-verb compounds with the same morphology. However, the fact that *-ed* object-verb compounds have a lower acceptability rate than *-ed* adjunct-verb compounds is surprising. Given that the processing of object-verb compounds requires fewer applications of morphological merger than adjunct-verb compounds, the acceptability rate of the latter is expected to be higher than the acceptability of adjunct-verb compounds, which require additional applications of morphological merger. This could be attributed to independent factors, namely the complexity added by the processing of passive morphology *-ed* in a bare object-verb configuration. In contrast, the adjunct-verb structure would provide the functional projection facilitating the processing of NV *-ed* compounds. The results of this second experiment indicate that I-complexity is structure dependent, thus it is a function of the recursive application of morphological merger, and it is not dependent on the number of occurrences of morphemes. However, further work is required to investigate the interaction between the complexity brought about by derivation and compounding.[17]

17. Frank & Bod (2011) argue that a sentence's hierarchical structure, unlike many other sources of information, does not noticeably affect the generation of expectations about

4.3 Summary

I-complexity effects are observed experimentally on the basis of the processing of complex verbs in French and NV-compounds in English. The RTs for verbs including prefixes occupying a higher hierarchical position in the structure are significantly longer than those observed for verbs with prefixes occupying a lower position in the structure. Likewise, differences in acceptability judgements are observed for novel object-verb and adjunct-verb compounds indicating that compound processing is sensitive to I-complexity as well.

Given I-language (Chomsky 1986, 2001), morphological complexity is not corpus-based. This is so because I-language – the mentally represented linguistic knowledge – is not occurrence-dependent. Languages that differ with respect to statistical E-complexity may share the same I-complexity. I-language complexity cannot be calculated via corpus-based analyses because such analyses do not necessarily rely on number of occurrences of affixes or roots. Morphological complexity is brought about by I-language computation. It is based on the recursive application of morphological merger, which may not necessarily be spelled out by overt morphological forms. I-complexity can be assessed by psycholinguistic experiments, as well as by experiments using brain-imaging techniques. Interestingly for our purposes, languages that are dissimilar with respect to the corpus-based statistical E-complexity may have similar I-complexity in the processing of morphological forms. This suggests that morphological complexity is not a monolithic concept and there is evidence supporting the Split Complexity Hypothesis.

5. Factors reducing complexity

The morphological complexity brought about by the derivation of structure including zero morphology must be reduced since zero-morphemes are generated by FLN but are not legible at the SM interface. In this section, I consider how morphological complexity brought about by zero-morphology can be reduced. I also revisit the results of related experimental work in this perspective.

Several studies show that derivational complexity is reduced by factors external to FLN (Chomsky 2005). Among the so-called "third factors", phases and

upcoming words. It is unclear whether the models used in these experiments, viz., probabilistic language models, are applicable to the structure of words, and more generally to sentence structure.

hierarchical prominence relations reduce derivational complexity. I-complexity can be brought about by the iterative/recursive application of the operations of the language faculty, and principles external to the language faculty reduce complexity. According to Chomsky (2005, forthcoming) derivational complexity is reduced by 'natural laws', such as phases and hierarchical prominence.[18] I will consider the role of linearization/externalization in the reduction of the complexity brought about by zero-morphology, that is, elements with semantic features but no phonetic features. Zero-morphology is relevant at the conceptual-intentional (CI) interface, but not at the SM interface. In the model of morphology of Di Sciullo (2005a, b), affixes can be located at the edge (specifier) or at the head of the minimal tree that they project according to their type (predicate, aspectual modifier, operator). Affixes in head positions have no phonetic features at the edge of their projection, which hosts semantic features, such as argument features. The semantically specified zero morphology derived by the operation of the language faculty is legible at the semantic interface. Zero morphology, however, is not legible at SM interface and is a source of complexity. To reduce this complexity, an externalization operation applies in the derivation to the SM interface.

In order to test this model, Di Sciullo & Fong (2005) used an LR shift-reduce parsing model[19] for the derivation of complex morphological expressions, such as *form-al-iz-able*, and considered the computational consequences of varying the edge-head linear order. Whether or not the edge of a morphological phase has phonetic features determines the linearization of morphological constituents, as evidenced in Di Sciullo (2005c) on the basis of the morphological properties of diverse languages, including languages with concatenative morphology, such as English and the Romance languages, languages with agglutinative morphology,

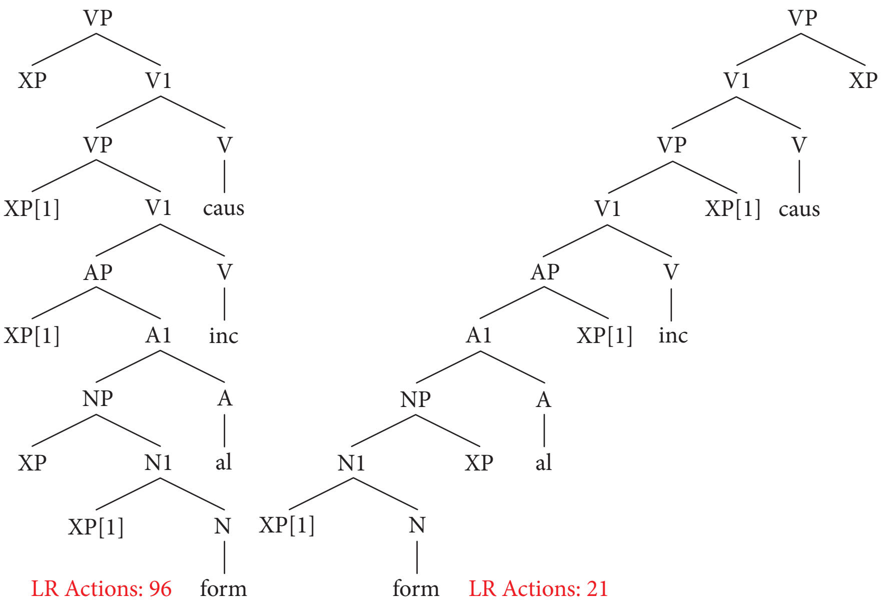
18. According to the derivation by phase model (Chomsky 2001, 2008), units of computation or 'phases' reduce the search space of the operations of the language faculty, in that they evacuate from the derivational workspace the material that is not subject to further derivation.

According to Chomsky (forthcoming), hierarchical prominence overrides string-linear locality in center-embedded contexts. For example, in *can eagles that fly swim?*, what is questioned is the ability of eagles to swim and not their ability to fly. The hierarchical closeness between the auxiliary *can* and the verb *swim* overrides the string linear proximity between that auxiliary and the verb *fly*.

19. An LR parser is a parser that reads input from left to right and produces a rightmost derivation. See Knuth (1965). An LR parser performs bottom-up parsing because it attempts to deduce the top-level grammar productions by building up from the leaves. LR parsing can be generalized as arbitrary context-free language parsing.

such as Turkish, as well as Niger-Congo languages, such as Yekhee, where affixes bear lexical tones.

The results of the computational experiments show that parsing efficiency increases when zero-morphology located at the edge of a morphological phase is retrieved from the work space of the parser by flipping the structure it projects to the right. This flipping operation applies outside of FLN, in the derivational space leading to the SM interface.[20]



(a) *Formalize* with left specifier

(b) *Formalize* with right specifier

Figure 2. Parse trees derived by the morphological parser for the parsing of the complex causative inchoative denominal verb *formalize*, differing with respect to the linearization of the edge (specifier) to the left (a) or to the right (b) of the root. Di Sciullo & Fong (2005)

Table 4 illustrates that parsing complexity grows exponentially if a zero-morphology edge precedes a root, while this is not the case if the zero-morphology edge is to the right of the root.

20. The morphological flipping (M-Flip) operation is defined as follows: *M-Flip (T):* Given a minimal tree T such that the Spec of T has no PF features, M-Flip (T) is the tree obtained by creating the mirror image of T. (Di Sciullo 2005a: 135)

Table 4. Number of LR actions necessary to parse expressions of increasing complexity according to whether zero-morphology is to the left or to the right of the root. Di Sciullo & Fong (2005)

Word	Items	LR actions	
		Left specifier	Right specifier
form	1	8	6
read-able	2	19	11
simpl(e)-i(f)-y	3	47	16
form-al-i(z)-e	4	96	21
form-al-i(z)-(e) able	5	172	26

These results support the hypothesis that the morphological complexity brought about by edges with zero-morphemes can be reduced by an operation external to FLN, namely M-Flip. This operation applies to morphological structures only when the edge of that structure has no features legible by the SM system. Thus, the I-complexity introduced by edges with zero-morphology can be reduced by the operation externalizing the results of the computation of FLN at the SM interface.

If I-complexity is generated by the recursive application of the operation of the language faculty and can be reduced by externalization, a natural question that comes to mind is how incoming E-complexity can be reduced.

A natural answer to this question is to take the language faculty to be the computational procedure that would reduce incoming morphological complexity. Exposed to complex morphological data, the operations of the mind/brain in conjunction with the principles reducing the complexity derive tractable structured sets. The reduction of E-complexity is naturally subject to the limitations of the mind/brain, including computation/storage limitations and short-term memory limitations, as discussed for example in Chomsky & Miller (1963). In this perspective, the language faculty, in conjunction with principles reducing complexity, reduces both I- and incoming E-complexity.

E-complexity is based on the occurrence of overt morphological material and can be measured by statistics. I-complexity, however, cannot be measured by statistics, as in some cases there is no overt morphological manifestation of the application of morphological merger, and results of psycholinguistic experiments indicate that processing complex morphological expressions is sensitive to the complexity brought about by FLN computation even in cases where no overt material is spelled out. These results, however, do not undermine the possibility that statistics and probability play a role in systems external to the language faculty, including the Language Acquisition Device, as argued in Yang (2002). In language acquisition, the LAD could play a role in the reduction of the E-complexity brought about by the incoming data flow, by reducing the choices for the development of a grammar, including the acquisition of morphology on the basis of exposure to complex morphological data. The LAD would also ease the acquisition of lexical items, and their storage in the mental lexicon, in the case of vocabulary items whose properties are not entirely regular. It might thus be the case that statistics and probability play a role in the systems external to FLN, including the LAD.

E-complexity can also be processed and reduced by what sub-serves mathematical operations in the mind/brain. If this is the case, it would be expected that different areas of the brain compute I- and E-complexity. Interestingly, recent neuro-anatomical results reported in Friedrich & Friederici (2009) indicate that the elicitation of syntactic judgments about the wellformedness of mathematical expressions (first order logic) and the elicitation of grammaticality judgments for linguistic expressions are not processed by the same areas of the brain. Further experiments are needed, however, to determine whether the elicitation of semantic judgments for mathematical expressions (truth-values) and for linguistic expressions (interpretations) is processed by different areas of the brain.

The Split Complexity Hypothesis articulates the notion of morphological complexity into an internal and an external dimension. This hypothesis leads us to investigate the properties of the dimensions of complexity, their measurement, their effects on processing, and their tractability. It also leads us to consider their role in our understanding of the relation between the language faculty and the external systems.

6. Discussion

In this paper, I isolated two perspectives on morphological complexity: the statistical information theoretic approach of Bane (2008), which I referred to as E-complexity, and an approach that relates morphological complexity to the length of a form's derivation, i.e. the number of applications of morphological merger, in the generative model of Di Sciullo (2005a). I termed this latter view I-complexity. I argued that languages differing in E-complexity might nonetheless have similar I-complexity, and I reviewed recent experimental work that relates I-complexity to processing. In closing, I would like to consider briefly how the two sorts of complexity are related.

The relation between I-complexity and E-complexity can be seen as a relation between the computational procedure of the language faculty and conceptualization/externalization.

I-complexity is a function of the iterative application of the operations of FLN. These operations derive structured-sets, which may include zero-morphology.

The psycholinguistic experiments discussed in Section 4.2 provide evidence that the mind/brain processes differences in hierarchical relations, which may not be associated with overt morphological material. If hierarchical representations must be legible at the CI interface but not at the SM interface, it is natural to assume that I-complexity is processed at the interface between the language faculty and the CI interface. I-complexity is not occurrence-dependent and it cannot be measured on the basis of externalized data. E-complexity, however, is a function of the density of externalized data, or string sets, and it is natural to assume that it is processed at the interface between the language faculty and the sensorimotor system, i.e. at the SM interface.

The dual nature of morphological complexity can be viewed as a consequence of the architecture of the language faculty, where the generative operations of FLN derive interface representations interpreted by the external systems, where morphological E-complexity is processed at the SM interface, and I-complexity is processed at the interface between the language faculty and the CI system. I- and E-complexity are related as the CI and the SM interfaces are related to FLN.

(28) FLN
CI SM

While E-complexity is based on overt morphological material and can be measured by statistics and probability, I-complexity cannot be measured by statistics, as in some cases there is no overt morphological manifestation of the application of morphological merger. I-language complexity is an effect of the iterative/recursive application of the operations of the language faculty, and results coming from psycholinguistic experiments indicate that human processing is sensitive to this complexity, as discussed in Section 4.2. The question arises as to whether statistics and probability play any role in the processing of the morphological expressions derived by FLN. To the extent that the activation of the operations of FLN does not rely on externalized data, statistics and probability are not part of FLN. The operations of FLN apply deterministically, each time a pair of elements undergoes morphological merger. This, however, does not undermine the possibility that statistics and probability play a role at the interface between the language faculty and the cognitive systems sub-serving mathematical computations, including the mathematical computations of the LAD.

References

Abramson, Norman. 1963. *Information Theory and Coding*. New York: McGraw-Hill.

Baker, Mark. 1988. *Incorporation: A Theory of Grammatical Function Changing*. Chicago: University of Chicago Press.

Bane, Max. 2008. "Quantifying and Measuring Morphological Complexity". *Proceedings of the 26th West Coast Conference on Formal Linguistics* ed. by Charles B. Chang & Hannah J. Haynie, 69–76. Somerville, Mass.: Cascadilla Proceedings Project.

Bar-Hillel, Yehoshua & Eli Shamir. 1960. "Finite-State Languages: Formal Representations and Adequacy Problems". *Bulletin of the Research Council of Israel* 8:3.155–166.

Bever, Thomas G. 1970. "The Cognitive Basis for Linguistic Structures". *Cognition and Language Development* ed. by John R. Hayes, 277–360. New York: Wiley & Sons.

Carden, Guy. 1983. "The Non-Finiteness of the Word Formation Component". *Linguistic Inquiry* 14.537–547.

Chaitin, Gregory J. 1987. *Algorithmic Information Theory*. Cambridge: Cambridge University Press.

Chomsky, Noam. 1956. "Three Models for the Description of Language". *IRE Transactions on Information Theory* 2:2.113–124.

Chomsky, Noam. 1970. "Remarks on Nominalization". *Readings in English Transformational Grammar* ed. by Roderick Jacobs & Peter Rosenbaum, 184–221. Waltham, Mass.: Blaisdell.

Chomsky, Noam. 1986. *Knowledge of Language.* New York: Praeger.

Chomsky, Noam. 1995. *The Minimalist Program*. Cambridge, Mass.: MIT Press.

Chomsky, Noam. 2001. "Derivation by Phase". *Ken Hale: A Life in Language* ed. by Michael Kenstowicz, 1–52. Cambridge, Mass.: MIT Press.

Chomsky, Noam. 2005. "Three Factors in Language Design". *Linguistic Inquiry* 36:1.1–22.

Chomsky, Noam. 2008. "On Phases". *Foundational Issues in Linguistic Theory: Essays in Honor of Jean-Roger Vergnaud* ed. by Robert Freidin, Carlos Peregrín Otero & Maria Luisa Zubizarreta, 133–166. Cambridge, Mass.: MIT Press.

Chomsky, Noam. forthcoming. "The Poverty of the Stimulus: Unfinished Business". *Interfaces in Language Design* ed. by Anna Maria Di Sciullo, Cambridge, Mass.: MIT Press.

Chomsky, Noam & George A. Miller. 1963. "Introduction to the Formal Analysis of Natural Languages". *Handbook of Mathematical Psychology* ed. by R. Duncan Luce, Robert R. Bush & Eugene Galanter, vol. II, 269–231. New York: Wiley & Sons.

Corbett, Greville G. & Matthew Baerman. 2010. "Deep Irregularity: When the Expected Lexical Splits Follow the Wrong Pattern". Paper presented at the 14th International Morphology Meeting. Budapest, Hungary, May 13–16, 2010.

Culy, Christopher. 1985. "The Complexity of the Vocabulary of Bambara". *Linguistics and Philosophy* 8.345–351.

Dahl, Östen. 2004. *The Growth and Maintenance of Linguistic Complexity*. Amsterdam & Philadelphia: John Benjamins.

Di Sciullo, Anna Maria. 1997. "Prefixed-Verbs and Adjunct Identification". *Projections and Interface Conditions: Essays in Modularity* ed. by Anna Maria Di Sciullo, 52–74. New York: Oxford University Press.

Di Sciullo, Anna Maria. 2005a. *Asymmetry in Morphology*. Cambridge, Mass.: MIT Press.

Di Sciullo, Anna Maria. 2005b. "On Affixal Scope and Affix-root Ordering in Italian". *Romance Languages and Linguistic Theory 2005* ed. by Sergio Baauw, Frank Drijkoningen & Manuela Pinto, 99–114. Amsterdam & Philadelphia: John Benjamins.

Di Sciullo, Anna Maria. 2005c. "Affixes at the Edge". *Canadian Journal of Linguistics* 50.83–117.

Di Sciullo, Anna Maria. 2009. "Why are Compounds Part of Natural Languages: A View from Asymmetry Theory". *Handbook of Compounds* ed. by Rochelle Lieber & Pavol Štekauer, 145–177. Oxford: Oxford University Press.

Di Sciullo, Anna Maria. 2011. "A Biolinguistic Approach to Variation". *The Biolinguistic Enterprise: New Perspectives on the Evolution and Nature of the Human Language Faculty* ed. by Anna Maria Di Sciullo & Cedric Boeckx, 305–328. Oxford: Oxford University Press.

Di Sciullo, Anna Maria & Sandiway Fong. 2001. "Asymmetry, Zero Morphology and Tractability". *Proceedings of the 15th Pacific Asia Conference on Language, Information and Computation. (PACLIC 15)* ed. by Benjamin K. T'sou, Olivia O. Y. Kwong & Tom B. Y. Lai, 61–72. Hong Kong: City University of Hong Kong.

Di Sciullo, Anna Maria & Sandiway Fong. 2005. "Morpho-Syntax Parsing". *UG and External Systems* ed. by Anna Maria Di Sciullo, 247–268. Amsterdam: John Benjamins.

Di Sciullo, Anna Maria & Dana Isac 2008. "The Asymmetry of Merge". *Biolinguistics* 2:4.260–290.

Di Sciullo, Anna Maria & Roumyana Slabakova. 2005. "Quantification and Aspect". *Perspectives on Aspect* ed. by Henk J. Verkuyl, Henriette de Swart & Angeliek van Hout, 61–80. Dordrecht: Springer.

Di Sciullo, Anna Maria & Naoko Tomioka. In press. "Compound Representation at the Interface". *Proceedings of Generative Linguistics in Poland: GLiP-6*. Cambridge: Cambridge Scholars.

Di Sciullo, Anna Maria & Edwin Williams. 1987. *On the Definition of Word*. Cambridge, Mass.: MIT Press.

Frank, Stefan L. & Rens Bod. 2011. "Insensitivity of the Human Sentence-Processing System to Hierarchical Structure". *Psychological Science* 22:829–834.

Friedrich, Roland & Angela D. Friederici. 2009. "Mathematical Logic in the Human Brain: Syntax". *PLoS ONE* 4:5.e5599. doi:10.1371/journal.pone.0005599.

Fodor, Jerry A., Thomas G. Bever & Merrill F. Garrett. 1974. *The Psychology of Language: An Introduction to Psycholinguistics and Generative Grammar*. New York: McGraw-Hill.

Goldsmith, John. 2001. "Unsupervised Learning of the Morphology of a Natural Language". *Computational Linguistics* 27:2.153–198.

Goldsmith, John. 2006. "An Algorithm for the Unsupervised Learning of Morphology". *Natural Language Engineering* 12.1–19.

Hale, Kenneth & Samuel Jay Keyser. 1993. "On Argument Structure and the Lexical Expression of Syntactic Relations". *The View from Building 20* ed. by Kenneth Hale & Samuel Jay Keyser, 53–110. Cambridge, Mass.: MIT Press.

Halle, Morris. 1970. "On Meter and Prosody". *Progress in Linguistics* ed. by Manfred Bierwisch & Karl Erich Heidolph, 64–80. The Hague: Mouton.

Hauser, Marc D., Noam Chomsky & W. Tecumseh Fitch. 2002. "The Faculty of Language: What Is It, Who Has It, and How Did It Evolve?". *Science* 298.1569–1579.

Juola, Patrick. 1998. "Measuring Linguistic Complexity: The Morphological Tier". *Journal of Quantitative Linguistics* 5:3.206–213.

Juola, Patrick. 2007. "Assessing Linguistic Complexity". *Language Complexity: Typology, Contact, Change* ed. by Matti Miestamo, Kaius Sinnemaki & Fred Karlsson, 89–108. Amsterdam & Philadelphia: John Benjamins.

Kayne, Richard. 1994. *The Antisymmetry of Syntax*. Cambridge, Mass.: MIT Press.

Knuth, Donald. 1965. "On the Translation of Languages from Left to Right". *Information and Control* 8:6.607–639.

Kolmogorov, Andrey N. 1965. "Three Approaches to the Quantitative Definition of Information". *Problems in Information Transmission* 1.1–7.

Langendoen, D. Terence. 1981. "The Generative Capacity of Word-Formation Components". *Linguistic Inquiry* 12:2.320–322.

Lasnik, Howard. 2011. “What Kind of Computational Device is the Human Language Faculty?”. *The Biolinguistic Enterprise: New Perspectives on the Evolution and Nature of the Human Language Faculty* ed. by Anna Maria Di Sciullo & Cedric Boeckx, 354–365. Oxford: Oxford University Press.

Li, Ming & Paul M.B. Vitanyi. 1997. *An Introduction to Kolmogorov Complexity and its Applications.* 2nd ed. New York: Springer.

McWhorter, John H. 2001. “The World's Simplest Grammars are Creole Grammars”. *Linguistic Typology* 5:2–3.125–166.

Milin, Petar, Victor Kuperman, Aleksandar Kostic & R. Harald Baayen. 2009. “Paradigms Bit by Bit: An Information Theoretic Approach to the Processing of Paradigmatic Structure in Inflection and Derivation”. *Analogy in Grammar: Form and Acquisition* ed. by James P. Blevins & Juliette Blevins, 214–252, Oxford: Oxford University Press.

Moscoso del Prado Martín, Fermín, Aleksandar Kostic & R. Harald Baayen. 2004. “Putting the Bits Together: An Information Theoretical Perspective on Morphological Processing”. *Cognition* 94.1–18.

Nichols, Johanna. 1992. *Linguistic Diversity in Space and Time*. Chicago: University of Chicago Press.

Nichols, Johanna. 2009. “Linguistic Complexity: A Comprehensive Definition and Survey”. *Language Complexity as an Evolving Variable* ed. by Geoffrey Sampson, 109–124. Oxford: Oxford University Press.

Pullum, Geoffrey K. & Hans-Jörg Tiede. 2010. “Inessential Features and Expressive Power of Descriptive Metalanguages”. *Features: Perspectives on a Key Notion in Linguistics* ed. by Anna Kibort & Greville Corbett, 272–292. Oxford: Oxford University Press.

Rivero, Maria Luisa. 1992. “Adverb Incorporation and the Syntax of Adverbs in Modern Greek”. *Linguistics and Philosophy* 15.289–331.

Rosen, Sara. 1989. *Argument Structure and Complex Predicates*. Ph.D. dissertation, Brandeis University, Waltham, Mass.

Shannon, Claude E. 1948. “A Mathematical Theory of Communication”. *Bell System Technical Journal* 27.379–423, 623–656.

Shieber, Stuart. 1985. “Evidence Against the Context-Freeness of Natural Language”. *Linguistics and Philosophy* 8.333–343.

Shosted, Ryan K. 2006. “Correlating Complexity: A Typological Approach”. *Linguistic Typology* 10:1.1–40.

Solomonoff, Ray J. 1964. “A Formal Theory of Inductive Inference”. *Information and Control* 7:1.1–22.

Spencer, Andrew. 1995. “Morphological Operations”. *The Handbook of Morphology* ed. by Andrew Spencer & Arnold M. Zwicky, 123–143. Oxford: Blackwell.

Tsapkini, Kyrana, Gonia Jarema & Anna Maria Di Sciullo. 2004. “The Role of Configurational Asymmetry in the Lexical Access of Prefixed Verbs: Evidence from French”. *Brain and Language* 90.143–150.

Yang, Charles. 2002. *Knowledge and Learning in Natural Language.* Oxford: Oxford University Press.

Zipf, George K. 1949. *Human Behavior and the Principle of Least Effort*. Cambridge, Mass.: Addison-Wesley. (Repr. New York: Hafner, 1965.)