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Word storage and computation

Abstract: The goal of this chapter is to assess some representative morphological theories with respect to their compatibility with results coming from psycholinguistic experiments. We will concentrate mainly on the question of whether inflected words are computationally built by the addition of discrete units, called ‘morphemes’, or have to be treated as undecomposable wholes which relate to each other through connections with other words. The issue is complicated by two problems: the nature of morphemes as abstract units that anchor phonological and semantic information or symbolic Saussurean units, and the problem of whether inflected forms are decomposable at some level of analysis or must be stored as fully built forms.

Keywords: word storage, computation, morphological theory, lexical decision, frequency effect, morphological priming

1 Introduction

It is uncontroversial that a part of knowing a natural language involves learning an idiosyncratic set of stored units that are associated with three sets of information that cannot be derived by any rule, and hence are idiosyncratic: a set of formal features (standardly assumed to include entities like N, V, A, Tense, Plural number, etc.), a phonological representation and a semantic representation. The competence of a speaker is furthermore assumed to include a part that is stored and a part that is computed, which involves building complex structures from the stored units. This is, however, all that is uncontroversial, and virtually any aspect of the specific form in which the association happens, the way the units are combined and the richness with which these levels are represented in the lexicon is subject to a lively debate across morphological theories.

The immediate goal of this paper is to assess a number of influential theories in morphology with respect to the adequacy of the predictions they make with respect to storage and computation, as far as those predictions can be tested with the available tools established in the field of psycholinguistics.

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There are a number of problems that we face when assessing a morphological theory with experimental psycholinguistic tools. Morphological theories tend to stress the aspects of language known since Chomsky (1957) as ‘competence’, that is they aim to capture the abstract language capacity of an idealized speaker/hearer and to arrive at a generalization of morphology that is valid across languages, morphological systems and individual speakers. In contrast, they rarely introduce questions related to ‘performance’, i.e. the processing and parsing of speech in production and perception, that are central in psycholinguistic research. Also, morphological theories are normally designed from a speaker’s perspective, and are much more explicit and clear when it comes to answering the question of how a speaker produces new words or the right form of the word given a context, than they are on the issue how the hearer or reader reconstructs, from the sequence that is received, the right grammatical and semantic properties that the word stands for. In contrast, much psycholinguistic research on the processing of inflected words has focused on data from single-word reading and hence on the reader perspective. Related to this issue is the problem that morphological theories might not be specific enough to derive precise predictions that would be testable in a psycholinguistic experiment – a problem we will see exemplified in some of the morphological theories discussed in this chapter. While morphological theories might pose some challenges for the psycholinguist eager to test them, morphological theorists often refrain from using data obtained in a psycholinguistic experiment as evidence for or against specific theoretical assumptions. Instead, theoretical considerations are generally based on intuitive insights or grammaticality judgements (cf. Penke and Rosenbach 2007 for discussion). In fact, psycholinguistic data, as all data, are ‘noisy’ as behavior in an experimental setting is not only influenced by the linguistic issues at stake but is potentially influenced by a number of factors relating to the subject, the experimental setting, or the environment in which the experiment takes place. How successful the influence of such interfering factors can be reduced is largely dependent on the experimenter’s aptitude. Whether or not experimental data can be considered a solid piece of evidence or whether it is flawed by factors not sufficiently controlled in the experimental setting might be difficult to assess for theoreticians unfamiliar with experimental procedures and data. The aim of our paper is to bridge this gap by showing how morphological theories can be tested by psycholinguistic data and which type of evidence would bear on theoretical assumptions.

In our exposition of storage and computation in morphological theory and psycholinguistic experimentation, we will focus on inflection rather than derivation. One main reason for this is that we consider the status of inflection to be less controversial, and hence better suited for an overview: its obligatoriness of application makes inflection a likely candidate for computation. In contrast, when the

divide between storage and computation is assessed in derivational morphology, it is less evident what one should be looking for, as there are degrees of productivity as well as abundant gaps and cases of affix rivalry dependent on fine-grained semantic or grammatical differences between affixes that are roughly synonymous.

Before moving to the overview of the relevant theories that we have singled out in this chapter, a couple of caveats are in order.

1.1 What are the units?

This chapter deals with the divide between storage and computation, so we must start by providing cursory definitions of the two concepts, which will be developed later (see in particular Section 1.2, where we will see that what is considered ‘computation’ is subject to a lot of debate).

- a) A form is stored if it is listed as a unit (with or without internal structure).
- b) A form is computed if it is the output of some operation that takes units as its input.

This divide, thus, crucially depends on whether something is a stored unit; therefore, the first question becomes to determine what the units are.

The answer is not trivial. A central concern is whether the minimal units are words, something bigger than the word or something smaller than the word. The main question is whether a form like (1) has to be taken as one single unit or two.

(1) boys

If (1) is one single unit, that unit has been called, for lack of a better term, ‘word’, with well-known complications that question whether (1) is a unit only at a phonological level or whether its atomicity extends also to other components of grammar. For instance, it is quite clear that (1) is not an atom from a semantic perspective, as it denotes at least two notions: plurality (roughly ‘more than one’) and a particular class of animate entities defined through age and biological sex. It is more controversial whether (1) is also an atom from a syntactic perspective (see Julien 2007; Williams 2007 and Embick and Noyer 2007 for different views).

Example (1) has also been analyzed as (at least) two units, in which case the term ‘morpheme’ is used: an inflectional marker for ‘Number’ (-s) and a base categorized as a noun (*boy*). If one follows that route, the conclusion is that, *ceteris paribus*, the minimal units that are stored are smaller than words. Words, understood as (structured) sets of morphemes, might be stored when the semantic or phonological information associated with them is not identical to those associated

with their individual morphemes, as in (2), where the meaning of the word would be claimed to be underivable from the meaning of its composing morphemes: this is known as Demotivation of Meaning, Lexicalization or Non-Compositionality.

- (2) understand ($\neq$ stand under something)

Another situation where theories that accept morphemes as minimal units could allow for a storage of a full form is irregular forms.¹ Consider (3). Here, the morphophonology of the form does not allow for a straightforward segmentation into two units, each corresponding to a different morpheme.

- (3) a. went (go)
b. wrote (write)
c. came (come)
d. slept (sleep)

Finally, other theories have suggested that the stored units might be bigger than words. Baayen, Milin, Durdevic, Hendrix, and Marelli (2011) have argued that the meaning of words or morphemes is crucially dependent on the linguistic context,

¹ Note that in theoretical approaches, generally different subsets of irregular forms receive a different treatment. One crucial divide in approaches that concentrate on the way in which sets of morphosyntactic features are identified with morphophonological exponents is the one that is found between forms like *feet* and forms like *children*, to give two examples of English plural marking. In the second case it is still possible to segment two exponents (*child*, albeit with a phonological change in its vowel, and *-ren*); in the first case, in contrast, in most analyses there is only one exponent that expresses plural through a change in the vowel of the root. Ignoring analyses where plural is expressed in this case as a floating feature (e.g., [front]), only one synthetic form would in such cases correspond to what presumably are two distinct morphosyntactic units. In many approaches each of these two cases are analyzed differently: the *feet*-cases as one exponent corresponding to two morphosyntactic units, unified in one single position of exponence through fusion (Halle and Marantz 1993), spanning (Ramchand 2008), phrasal spell out (Caha 2009; Fábregas 2014a) or conflation (Hale and Keyser 2002), and the *children*-cases essentially as cases where one exponent selects a marked exponent for plural when the two exponents are immediately adjacent to each other (therefore, when there is no additional exponent between the two of them), and thus as a case of morphologically-conditioned allomorphy (Embick 2010). Note, however, that both cases have the same status from the perspective that we are adopting here: in both cases, the speaker producing the form will be facing a situation where the general rule does not apply and the special status of the root has to be taken into account in order to produce a non-general marking of the plural. Similarly, in both cases the child acquiring the language would have to get direct evidence from the input that the general plural rule is not applied to a subset of roots that include *foot* and *child*, and the frequency with which these irregular forms are found in the input will be crucial (cf. Penke 2006; Marcus et al. 1992: 55ff.).

even ignoring idiomatic cases; if one goal of storage is to associate a phonological (or orthographic) representation to an idiosyncratic meaning, then it follows that at least at some stage any word or morpheme has to be stored with some context in order to register its meaning. Without going to that extreme, DiSciullo and Williams (1987) already noted that syntactic phrases need to be stored in the lexicon whenever they have an idiomatic meaning (4).

(4) to lose one's head

The problem of identifying the minimal units of storage, as can be seen already from this cursory overview, which will be expanded throughout the chapter, is severe. But it gets worse. As the astute reader might have already noticed, the question of whether the forms in (3) are in principle decomposable cannot be answered unless one has decided what counts as a 'morpheme', and more specifically, how abstract a morpheme representation has to be.

There is one intuitive sense in which 'morphemes' correspond to minimal Saussurean signs, Janus-like objects with two sides: a phonological representation and a meaning. This is the traditional view of the morpheme as the minimal sign (cf. Hockett 1947, 1954; Jespersen 1933). In such case one expects, assuming a naive phonological component, that none of the forms in (3) are decomposable; if our system contains a more sophisticated phonological component, allowing floating features, subsegmental representations and readjustment rules (Chomsky and Halle 1968), (3b), (3c) and (3d) could be decomposable. In this kind of 'grounded' view of morphemes, they could be represented as (5).

(5)

It is well-known, however, that this sign-definition of morpheme runs into problems (see Anderson 1992: Chapter 3; Aronoff 1976 and Stump 1998, 2001: Chapter 1 for overviews). The classical notion of a morpheme as a Saussurean sign was questioned very early in the morphological tradition. The discussion is typically traced back to a controversy between Hockett (1947) and Nida (1948). Inside a structuralist framework, the main point of contention between these two authors had to do with the status that non-segmentable morphological marking should have in the theory. Non-segmentable morphological marking involves, roughly, all cases where it is impossible to find definite boundaries inside a complex word such that a morpheme is isolated to the right, and another one to the left. (6) is a case of segmentable morphology:

(6) eat-s

Cases of non-segmentable marking are quite varied. They include, but are not restricted to, cases where morphological complexity is expressed through a segmental or suprasegmental alternation in the base, i.e. replacive morphology, as in (7a), with suppletion being the most extreme case of this, as in (7b).

- (7) a. wât ~ wât [Shilluk, Nilotic]
 house.SG house.PL
 b. go ~ went

In fact, a good deal of the debate refers to how (7b) should be analyzed. Hockett (1947), who argued for a traditional view of morphemes, proposed an analysis that Nida (1948) considered counterintuitive: the past tense information is expressed through a zero morph (a morpheme without phonological information). Once this morpheme is present in the word, it selects a marked allomorph of the root:

(8) go-∅ > went-∅

Nida criticizes, explicitly, that this analysis forces a paradoxical conclusion: the alternation that we can see on the surface (*go ~ went*) does not directly encode any grammatical distinction, while the grammatical contrast between present and past is not overtly marked.² Nida (1948) concludes, then, that, if we do not want to fall into this kind of paradox, the inescapable conclusion should be that morphosyntactic alternations are submorphemic. The consequences of what Nida intended to say³ are less clear than what the branch of analyses that derived from Nida's observations have actually said, which involves denying the reality of morphemes as stored, Saussurean signs. Thus, theories that side with Nida in this respect have denied that 'morphemes' have the status of units of morphological analysis. These approaches claim that the smallest units of morphological analysis are words, and

² Note that Chomsky and Halle's (1968) analysis of suppletion as phonological change from one single underlying abstract representation is in essence an offspring of Hockett's account. See Bermúdez-Otero (2012) for a criticism of approaches to the lexicon where hyperabstract representations and rules are proposed: they make acquisition essentially impossible.

³ Surprisingly, the essence of what Nida said is compatible with some in principle remote approaches, such as some versions of Generative Semantics (see specifically McCawley 1968), where it is proposed that single morphemes are tree structures whose nodes codify different (semantic) pieces of information. Modern Nanosyntax (Starke 2009) also shares this conception of morphemes as complex objects (phrases), which lets contrasts emerge as submorphemic alternations between heads.

then the question is whether ‘morphemes’ have reality at some non-morphological level. Some (Anderson 1992; Aronoff 1976) admit that ‘morphemes’ can be units at a phonological level, while some do not even recognize them as units of this sort (Word and Paradigm approaches; Stump 1993, 2001). However, they agree that proper symbolic decomposition should not be applied below the word level. For instance, Aronoff (1976) drew attention to examples like (9), where a naive decomposition of the words into a prefix and a verbal stem would face the challenge of assigning some concrete, consistent meaning to each morpheme.

(9) re-stitute, pro-stitute, in-stitute, con-stitute

Aronoff’s conclusion, further developed in Aronoff (1994), is that morphemes have to be viewed as abstract objects, not traditional signs.

Not all researchers feel that the above-mentioned facts necessarily mean that morphemes cannot be used as units. In order to account for the mismatches between marking, meaning and function at the word level, Beard (1995), Halle and Marantz (1993) or Ackema (1995) argued for the Separation Hypothesis. Separationist theories do not treat morphemes as signs, but as some sort of abstract placeholders where phonological and semantic information is anchored. Instead of the representation in (5), the schematic view of the morpheme could be represented as (10).

(10) Form —————> MORPHEME <———— Meaning

This, as we will see, has potentially crucial consequences: the same morpheme can be associated with different meanings and forms (e.g., ‘plural’, in an abstract sense, will not always mean ‘more than one’, as in *to have the brains*), and it will open the door to treating all forms in (3) as decomposable at some abstract level, with additional operations making the decomposition not evident from the surface. Thus, the nature of the minimal units that one assumes to be stored is inseparable from the question of how abstract these units are; we will get back to this issue in Section 1.3.

1.2 What is stored and what is computed?

With respect to the second issue, the division of labor between storage and computation, it can be interpreted in two different ways. First, the division can be interpreted as whether complex words are composed out of morphemes or not. This treats the division between ‘regular’ and ‘irregular’ as meaning ‘decomposable’

and ‘non-decomposable’, essentially. This conception of computation as regularity is typical for theories where the units are morphemes. For instance, in Wunderlich’s (1997) Minimalist Morphology framework (henceforth, MM), regular words such as *classified* are computed by combining morphemes following a restricted set of rules, and irregular words such as *went* are stored as unanalyzed units. We will see that, in this sense, a theory that does not treat morphemes as units, such as Anderson’s (1992) A-morphous Morphology, would be classified as a theory where every word is stored, irrespective of whether it is regular or irregular.

Theories where words (but not morphemes) are units also can involve computation, but in a second sense. In this second interpretation, it refers to whether a word needs to be stored as a lexical entry or not. Take A-morphous Morphology (Anderson 1992): in this theory the form of a regular word would be a predictable effect of the application of a rule to a base, because the rule comes with a description of the kind of phonological change that it triggers on the base. Hence, full regular forms are not listed inside lexical entries, even if no morphemes are segmented inside them. It is crucial to differentiate this notion of computation from the previous one, where it equals ‘segmentability’. In the A-morphous Morphology proposal, an ‘irregular’ form is a form listed as (part of) a lexical entry, like in the previous approach to storage, but computation does not amount to segmentability.

The issue whether being regular implies being decomposed or computed already shows that the assessment of the adequacy of theories through psycholinguistic methods is not trivial: each field has given a different amount of attention to this debate, and the ways of interpreting the divide lead to different classifications of theories.

1.3 The abstractness problem: Unitary and separationist theories

There is a third complication to the task that we undertake in this chapter. As we saw in Section 1.1, some of the theories that acknowledge the existence of morphemes adhere to the Separation Hypothesis. The initial motivation for Separationism is to be able to treat the surface mismatches between marking, meaning and function without giving up the notion of ‘morpheme’ as the relevant unit of analysis. This comes at the cost of dissociating the morphosyntactic side of the morpheme (the formal grammatical features they encode) from its morphophonological side (the kind of phonological marking, if any, that they trigger on the base). Several principles have been proposed that present this hypothesis: Beard (1995), who uses Separation; the Feature Disjointness Hypothesis

in Embick (2000), and the Separationist Hypothesis in Ackema and Neeleman (2004). These approaches share one property: they explicitly propose that the level that deals with the way in which grammatical and semantic properties are defined is distinct from the level that determines how these properties are going to be spelled out by segments with (possible) phonological information. Thus they all would agree that, in some way, grammar has to distinguish between two kinds of objects, in practice ‘distributing’ lexical entries across modules of the grammar:

- (11) a. [plural], [past], [noun], [imperfective], [feminine]. . .
 b. -s, -ed, -ation, -ing, -ess. . .

These two lists of units represent separate sides of what traditionally was considered a morpheme, and grammar must have some procedure whereby the units in one level are associated with the units in the other level, sometimes not in a one-to-one fashion. In Embick’s Feature Disjointness Hypothesis, formulated inside Distributed Morphology (Halle and Marantz 1993), the modules are ordered with respect to each other and each one of the two lists in (11) are accessed at different times, with the structural properties of the word being defined at an early level, and the abstract units getting spelled out later (a procedure known as Late Insertion, cf. Bonet 1991; Noyer 1992). In this proposal, this spell-out level is where ‘morphemes’ are defined:

- a. specific items, like *-ed*, *went* or *-s* are introduced in morphosyntactic environments that match the features to which they are associated;
- b. these items can carry with them idiosyncratic morphological properties (e.g., the conjugation class of a verb, or the declension class of a noun) and idiosyncratic, non-predictable semantic information (e.g., that *cat* refers to a particular animal, while *dog* refers to another one);
- c. the phonological and semantic computation takes into account these idiosyncratic properties and their phonological information.

Separationist theories present one problem for the goals of this chapter: what can be decomposed at one level might be not decomposed at another one. In a separationist model, there is a divorce between the structural properties of the word at an abstract level, and their surface realization. In irregular verbs, for instance, a separationist model proposes that the underlying structure of the form is identical in a regular and in an irregular verb, and the difference emerges at spell out. Thus, at one level (the abstract representation) one should not expect differences between regulars and irregulars; at the other level (the surface materialization) one expects differences between the two classes of verbs, because the regular form will spell out with more than one morpheme,

while the irregular will be spelled out by one single synthetic morpheme. The problem is this: the experimental predictions are less clear unless one can guarantee that the experimental design targets only morphophonological or morphosyntactic representations. At present, however, it is unclear whether the experimental methods currently employed in psycholinguistic research allow for selectively targeting storage or computation of inflected words at the level of morphophonological or morphosyntactic representations.

'Unitary' morphological theories, in contrast, do not incorporate the Separation Theory. In these theories, morphemes (or words) are signs, and there is only one list of stored items with entries that already contain information about grammatical, phonological and semantic properties. Good examples of these theories are Halle (1973) or Wunderlich's MM (Wunderlich 1997).

Let us now move to a closer examination of the existing theories.

2 Theoretical approaches to morphological decomposition

In this section we will introduce the positions that have been advocated in morphological theories with respect to the issue whether at least some inflected forms are decomposed into smaller units. If that is the case, the next question is whether this decomposition is identifying morphemes or some other units of analysis, such as the exponent.

In order to carry out the comparison of the relevant theories, we will concentrate on four questions:

- a. What is stored in theory X?
- b. Is the storage divided in one single list (unitary) or in several (separationist)? (that is, is all stored information kept in the same place, or is it distributed across different modules, each one accessed at distinct points?)
- c. What is computed?
- d. What kind of computation is relevant?

2.1 Radical decomposition

A proposal that accepts the Separation Hypothesis and Late Insertion can claim that all words that are morphosyntactically complex are decomposed at an abstract level. This includes cases that are irregular in a traditional sense. When

such approaches argue that both words and phrases are generated by the same component of grammar, they are labeled ‘Neo-constructionist approaches’.

In a Neo-constructionist model, the main idea is that – if one considers only the morphosyntactic side of the word – any inflected word is decomposable. In fact, this model gives primacy to the morpheme above the word: morphemes, as morphophonological objects that spell out syntactic heads, are the units that compete with each other, and no independent object ‘word’, distinct from ‘phrase’ at a morphosyntactic level, is accepted. Said more clearly: no word would be stored as a unit at the relevant level.⁴ In summary:

- a. Regular and irregular forms share the same morphosyntactic representation.
- b. Regular and irregular forms are differentiated only by the nature of the spell-out procedure they receive.
- c. The units of analysis are syntactic heads, spelled out as single morphemes.
- d. Heads/morphemes are combined through syntactic merge.

Distributed Morphology (DM) is an example of this kind of theory. In this clearly separationist approach, at least two kinds of units have to be distinguished: abstract sets of features (morphosyntax) and exponents (morphophonology). Computation here is syntactic and morphophonological: the sets of features are merged together by syntax, and how they are spelled out is determined by different kinds of rules. In DM there is one single generative component of grammar – syntax – that puts together syntactic heads, which at this point only contain abstract features like those in (12).

(12) [v], [T^{past}], [√]

Syntax combines these heads through binary merge, producing a tree structure like (13).

A past tense like *wrote* and a past tense like *classified* would be identical at this level: both regular and irregular words are, thus, computed in syntax. The

⁴ Lexical Integrity effects are treated as epiphenomena following from the phonological properties of the morpheme, or some semantic factors; see Lieber 1992; Embick and Noyer 2007.

differences emerge in the next level, when these heads are reinterpreted as positions of insertion for exponents, which introduce (among other idiosyncratic properties) specific morphophonological information. At that later level, lexical entries like those in (14) are accessed. These entries read the abstract features in (13) and check what exponent is associated with them. (14) represents the exponents involved in the regular form *classified*.

- (14) a. *-ed* <--> [T^{past}]
 b. *-ify* <--> [v]
 c. *class-* <--> [√]

Thus, (13) becomes (15) after Late Insertion of the exponents.⁵

DM claims that there is an additional level mediating between the syntactic and the phonological representation where several operations have to take place, and an extra level of readjustment rules taking place after the insertion of the exponents, where some other operations can happen. These two levels following or preceding the insertion of vocabulary items are responsible for irregular forms. Schematically, the order of levels is given in (16):

⁵ Note that we gloss over a potentially significant factor here: how deterministic the insertion of exponents is. If we look at (14), it is clear that there should be a very high number of exponents that in principle can be inserted in the root position: here insertion is not obviously deterministic (although see Borer 2013, who proposes that already in the syntax, roots are distinguished by a phonological index which determines later if the spell out will be done through one or another exponent). In contrast, presumably the only English exponent that can spell out the node T[past] alone will be *-ed*, so in this case insertion will be deterministic: only one exponent will correspond to the feature representation T[past]. The exponent corresponding to v is in an intermediate position: not any element can be introduced here, but there is a set of at least three items (*-ify*, *-ise*, *-en*) that can be used to verbalize a root. For this distinction between different kinds of exponents and the different conditions of insertion that affect them, see Harley and Noyer 1998.

(16) Abstract hierarchical structure

Consider first an irregular form like *wrote* (cf. Halle and Marantz 1993). DM treats this irregular form as the result of the application of a readjustment rule along the lines of (17), that is, a (morphophonological) operation that manipulates the morphophonological representation of an exponent in a particular context. Thus, there is a second computation at this level, where stored units (now exponents) are subject to an operation. Technical decisions aside, what is of relevance for us here is that this means that these irregular forms are derived by rule, involving therefore computation and not storage.⁶

(17) /aɪ/ --> /ou/ / X__Y [past]

For X = √write

There are only two differences between regular and irregular inflected forms, then, both becoming relevant after the exponents are inserted: the form needs a readjustment rule that a form like *classify* does not need to undergo and the verbal exponents that undergo the rule must be marked somehow in the exponent lexical list.

A more controversial issue is the less frequent suppletive alternations like *go ~ went*, which seem to be difficult to formalize as a mere morphophonological readjustment. For some time, it has been assumed in DM and similar approaches that a root element cannot vary so radically in its phonological content across spell out contexts (e.g., Borer 2013). For this reason, the standard analysis of these forms did not use readjustment rules of any kind. This kind of irregularity was treated as the result of an operation in the morphological component

⁶ In fact, see Embick and Halle 2005, where it is claimed that readjustment rules do not block the insertion of other exponents: consider *tol-d*, where *tell* has both undergone a readjustment rule and the past morpheme is overtly introduced.

followed by insertion of an exponent that cumulatively spells out Past and Verb (Halle and Marantz 1993: 129):

Thus, in this account the suppletive exponent has a separate lexical entry, even though at the morphosyntactic level it is still decomposed. In order to arrive at the morphological representation that allows the two syntactic heads T and v to be spelled out by one single form, the morphological component has to fuse these two heads in one single position of exponence. One aspect of this account that has been criticized is that it involves a certain degree of looking forward: the operation that fuses the two heads into one morpheme is triggered by the existence of a single exponent for the set T+v, even though that exponent has not yet been introduced. Needless to say, this account would expect a distinction between suppletive verbs and other irregular verbs, which still are derived by rules.

However, recently, Harley (2014), discussing data from Hiaki, has convincingly argued that suppletion can involve a root node. This step has the immediate consequence that the situation of suppletion in DM is unclear now, and could be implemented through readjustment rules. In such case, which is subject to debate still, all irregular verbs would be derived by rule.

2.2 No morphological decomposition

Other morphological theories (e.g., Anderson 1992; Aronoff 1976) have actually made the point that morphemes are simply convenient labels to talk about sets of segments inside words that we perceive as complex. They have no psychological reality and they have no place in a linguistic theory as primitives at a morphological level.⁷

⁷ But see Marantz 2013 for a different interpretation of Anderson 1992.

The common property of these theories is the proposal that the lexicon does not store morphemes. The minimal objects that can be stored in this component are words, which then, by definition, are presented without any kind of internal morphological structure. Whatever morphological information might be relevant for word external phenomena has to be specified in a morphosyntactic signature of the word.

Both Aronoff (1976) and Anderson's (1992) A-morphous Morphology accept that 'morphemes' can be phonologically segmented, but deny that they have the status of morphological primitives. Computation in A-morphous Morphology involves rules that take words as input and produce new words: this is restricted only to regular formations, while irregular forms still have their own stored lexical entry.

In Anderson, regular inflection is performed through the application of rules that take a base and apply some change to it, which can affect its semantics, grammatical distribution and phonological shape. What seems to be a 'morpheme' in the classical sense is part of the description of the base: precisely the kind of phonological change that the rule triggers in the base. Take (19) as a simplified illustration of this kind of rules.

(19) Word formation rule for regular past tense, English

$$\left[\begin{array}{c} V \\ \text{Past} \end{array} \right]$$

/X/-> /Xed/

Specifically, Anderson proposes that inflection is performed through Inflectional Word Formation Rules (Anderson 1992: 122–123):

[A] set of inflectional Word Formation Rules form part of the grammar, and operate to map lexical words (actually, lexical stems) onto fully inflected surface words. Such an inflectional Word Formation Rule takes as its input a pair {P, M}; this consists of a phonologically specified stem P from the lexicon [...] and the morphosyntactic representation M of some position in a Phrase Marker. [...] Each individual Word Formation Rule operates on the stem P so as to form a new stem P' that reflects the phonological stem (such as the addition of affixal material) associated with a part of the word's productive inflection. [...] Each rule may be regarded as a sort of generalization of the notion of 'morpheme', whose form (or signifiant) corresponds to the rule's Structural Change, and whose content (or signifié) corresponds to its Structural Description.

Let us stop here for a moment to ponder the consequences of this, and focus on the problem we advanced in Section 1.2 in respect of the two senses of 'stored' in theoretical morphology. First, this system might have something that could be abstractly interpreted as a 'morpheme', but its shape is not the one of a sign,

that is, it would not make any sense to talk about a lexical entry /ed/ associated with a past tense meaning. However, Anderson's system is still symbolic at another level: it produces regular forms through a rule, which codifies a set of possible phonological changes and associates these changes with a more or less specific grammatical and semantic change. In consequence, even though there are no stored entries for any morpheme, regular inflectional forms do not have an entry of their own, and in that sense they are not stored, but computed through a rule. If we restrict the notion of storage to the question of whether morphemes have separate entries and regular forms are computed by combining those morphemes, Anderson's theory is, however, a clearly non-decompositional theory where words are the only objects that can be stored.⁸ Note also that, as has been pointed out in other works (Williams 2007), Anderson's theory is to some extent separationist as it divides quite radically the syntactic aspect of the rule from its phonological effect.

What would be an example of a fully stored word in Anderson? It would be an irregular inflected word, such as the plural *oxen* instead of **oxes* (Anderson 1992: 132–134), or, by extension, *wrote* instead of **writed*. Anderson's proposal is that such irregular forms must be listed as stems inside the lexical entry of the base, and already associated with the maximal set of features that explains their distribution: *oxen* would be specified already as [+Noun, +Plural], as opposed to *ox*, which would lack the [+Plural] specification. A further principle of blocking of less specific forms by more specific forms would prevent the redundant **oxens* from being produced. Anderson further allows that the output of a rule (computed forms) becomes opaque over time if some unpredictable idiosyncrasies are associated with it. In that case, after some time the form would be stored as a stem with its own lexical entry. Grammatical change, then, can turn a computed form into a stored one.

⁸ In fact, being regular is, for Anderson (1992), just an illusion produced by the tendency to correlate common sets of segments that recurrently appear in words that share one piece of information with the expression of that piece of information. In other words, if speakers see that a segment /xy/ appears frequently in words that share the information [A], there is a psychological tendency to identify /xy/ as the way to denote (symbolically) [A]. But, as Anderson points out, this psychological tendency does not mean necessarily that grammar identifies /xy/ with [A]. In fact, he continues, this is anyways what would happen with phonaesthemes, that is, phonological segments that convey or suggest some concept (typically, 'small' and 'big') and tend to appear in words expressing that concept, such as high front vowels in words denoting smallness (*tiny*, *little*, *bit*, *kitten* ...). And yet, with these segments, no reasonable morphologist, even if they advocate that morphemes are units, would attempt to segment the high front vowels and associate them to an abstract representation [small].

Anderson's theory illustrates the fact that in some theories the terms 'decomposable' and 'computed' are independent: regular inflectional forms are computed, not stored, but they are not decomposable at a morphological level. Thus, Anderson (1992) is not a pure example of a non-symbolic theory for word formation.

In contrast, Rumelhardt and McClelland's (1986) Distributed Connectionist approach is a perfect example of a purely non-decompositional, non-symbolic approach where words are never decomposed at a morphological level: both regular and irregular forms are stored, and no rule is used to relate two word forms. Distributed Connectionism, as a program to study cognitive phenomena, proposes that production and recognition of forms is performed through an architecture of simple processing units – which are general information-processing devices – associated with each other through weighted connections of different strengths. Their view of how forms are related to each other is a pattern associator network (Kohonen 1977), which relates through connections a pool of basic forms (root forms in English) with a pool of output patterns related to past tense: the pattern associator contains a set of connections relating, with different strengths, input and output forms, until an optimal performance is reached and the strength of the connections becomes relatively fixed. In this system, there are typically three layers: the input layer, the hidden layer that intermediates between input and output by defining an internal representation, and the output layer that produces the appropriate behavior in the context. Note in (20), which is a feed-forward structure, that each unit is connected to each unit of the next layer; these connections are not of equal strength, though, but any cognitive process involves the parallel activation of several of these connections, in a cooperative fashion (see also Marzi et al. 2020, this volume and Pirrelli et al. 2020, this volume).

Simplifying matters now, in a connectionist model all words are stored, without internal segmentation, and related to each other through associative connections (as in 21). No different representation is assumed for regular and irregular forms,

and learning implies (a) learning new stored forms, such as *classified*, *cars*, *wrote* or *went* and, crucially, (b) manipulating the strength of the connection between two or more of these entries, so that one is registered as the past of the other, etc. Simplifying the claim to just pairs of words, the learner becomes trained in associating one form with the other, and each with its right meaning and distribution.⁹

2.3 Mixed approaches

There are also approaches that in one sense or the other claim that decomposition and absence of decomposition are both (simultaneously or alternatively) attested in the lexicon.

One early example where some complex words are stored as wholes and some are decomposed into morphemes, which have their own entry, is Halle (1973), where he sets the basis for what after him became the development of generative morphology (Lieber 1980; Scalise 1984; Siegel 1974, among many others). What is crucial for us in this approach is that Halle proposed a system where words are in principle put together compositionally through the addition of morphemes, but at a later level the result is compared to a list of full words, stored as units that might block the output of the rules that combine morphemes. Schematically (Halle 1973: 8), the sequence looks like this:

⁹ Building up on the original work of Rumelhart and McClelland (1986), connectionist modelers have set out to construct a multitude of different network models that claim to adequately simulate the different behavior observed for regular and irregular inflected forms in experimental research, although both regular as well as irregular inflected forms are represented and processed in a single associative network by identical mechanisms (see Marcus 2001 for an overview of such models). Recent developments include, for instance, the Naive Discriminative Learning (NDL) model (Baayen et al. 2011; see Plag and Balling 2020, this volume) and constructivist networks (cf. Penke and Westermann 2006). However, the literature is much too extensive and too specific to discuss the different models even cursorily. Interested readers are referred to Marcus 2001; Penke 2012a and Plag and Balling 2020, this volume.

The list of morphemes, paired with grammatical information about their properties, feeds the rules of word formation, which contain sets of rules dictating how those morphemes need to be combined. But of capital importance to Halle is the fact that individual words have idiosyncratic characteristics: next to 'regular' words like *arrival* ('the action of arriving'), other words of seemingly the same structure, $[V + al]_N$, have a special meaning, such as *transmittal*, restricted to transmitting official documents and not any kind of transmission. The role of the filter is to add these pieces of idiosyncratic information to the words productively generated by the rules, and even, sometimes, to mark some of the potential words as not subject to insertion in a tree structure (e.g., **derival*), that is, as not actual words. The dictionary, the final step in the sequence, contains the list of all words that actually exist in the language.

We mention Halle in this context because his theory has one crucial property of a mixed model: words can be generated (computed) and listed (stored). However, the contrast between regular and irregular does not coincide with computed vs. stored in Halle (1973). For instance, some irregularities – understood as idiosyncrasies that cannot be accounted for by word formation rules – would not be dealt with in the dictionary of words through the storage of the whole form, but would be accounted for by the filter component through a readjustment rule. Such is the case in (23), where the final $[t]$ of some bases becomes spirantized in a specific morphological context (see, for instance, Siegel 1974).

(23) president > presidential

Moreover, in Halle (1973) the dictionary contains fully inflected words, that is, not just stems like *eat*, but actually whole paradigms like $\{eat, eats, ate, eaten, eating\}$. This brings up a question: if complex words are taken directly from the dictionary, how do we know that they are stored as segmentable, internally complex units, and not just as full, atomic representations? Halle is in fact fully aware of the problem, and mentions it (Halle 1973: 16).

I have proposed above that the syntactic component has direct access to the dictionary; i.e., that the lexical insertion transformations take items from the dictionary rather than from the list of morphemes. Although the content of the dictionary is entirely determined by the content of the list of morphemes, the rules of word formation and the exception filter, there is no need to assume that these components are always fully

involved in every speech act. Instead it is possible to suppose that a large part of the dictionary is stored in the speaker's permanent memory and that he needs to invoke the word formation component only when he hears an unfamiliar word or uses a word freely invented. While this is by no means an exceptional occurrence, its frequency is quite low.

Interestingly, Halle is not explicit with respect to whether the storage in the dictionary is segmented or not. It is not implausible to think, however, that once the word is stored, and given that the list of morphemes is not accessed directly, the word should be stored as one atomic unit, and thus, without internal boundaries.

Thus, in Halle's proposal a word could be viewed as segmentable from one perspective, but as not segmentable from another one, depending on whether we are talking about words as members of the dictionary (which is closest to a lexical representation) or as the output of the word formation rules. This, again, shows that the question of storage can be seen in different ways inside a morphological theory.

If Halle's model is mixed because it allows both for computation and storage of the same word, other models are mixed in a simpler way, which allows one to establish more direct predictions with respect to the experimental results. These models claim that the list of exponents of a language contains both individual morphemes and whole words, with the second class being restricted to irregular forms like *wrote* or *went*.

Wunderlich's Minimalist Morphology (Wunderlich 1997) is an example of this kind of mixed model where regular forms like *spied* are computed by combining morphemes, while irregulars like *ran* have their own lexical entries as unanalyzed units. Morphemes are understood as signs, which means that in this system there is only one lexical list (as opposed to Distributed Morphology, for instance). Morphology is a generative component of grammar that takes individual entries and combines them, prototypically in a concatenative and compositional way that produces regular forms. Irregular forms, in contrast, are not built by any kind of computation, but are simply taken from the lexicon, where all their features are specified – as there is no separation hypothesis in MM. Once the word projects in a syntactic tree, all the features contained in the form will be checked against the relevant heads in syntax. Assume, for the sake of the argument, that *ran* has the features specified in (24):

(24) [Past, +external argument, verb]

This means that the inflected form, which in this case is stored as an undecomposed lexical entry, will have to license these features in syntax with the

heads that carry these pieces of information. These heads presumably would be V (lexical verb), v (responsible for defining the external argument) and Tense. In the case of forms like *wrote*, where DM used readjustment rules, MM uses a non-symbolic generalization, an inheritance tree associated with the lexical entry of the irregular verb, as in (25) which is a generalization aimed at capturing the vocalic changes in irregular strong verbs in German (Wunderlich 1992, 1996).

This captures, for instance, that in the paradigm of *werfen* ‘throw’, we predict *werf-* for a first person present indicative, *wirf-* for the present of the second person, *warf* for the past, *würfe* for the subjunctive and *-worfen* for the participle. Thus, in this theory there is a very clear cut between irregularity (stored in the lexical entry, non-symbolic) and regularity (computed through combination of morphemes via symbolic generalisations).

Finally, Nanosyntax is a Neo-constructionist framework that however falls into the mixed approaches to the extent that the exponent list contains entries for single morphemes, allowing decomposition of a complex word, but systematically also entries that correspond to a whole irregular word (Caha 2009; Dékány 2012; Fábregas 2007a, 2007b, 2009, 2014a, 2014b; Lundquist 2009; Muriungi 2008; Ramchand 2008; Ramchand and Svenonius 2014; Starke 2002, 2009, 2014a, 2014b, among others). In contrast to DM, however, the main proposal in Nanosyntax is that exponents are not necessarily introduced in heads – terminal nodes – but can actually correspond to the spell out of whole phrases. By assumption, each syntactic head in Nanosyntax contains only one (interpretable) feature. What this means is that, in contrast to DM, it is unnecessary to propose a list of stored elements for morphosyntax: those heads are not expected to be subject to variation in terms of their feature endowment, as they only carry one feature each. Thus, this approach only needs to assume one single idiosyncratic list, which contains exponents pairing the syntactic heads with phonological and conceptual-semantic content,

essentially defining which and how many heads each morpheme identifies. The representation of a verb in the past tense in this framework could roughly correspond to (26).¹⁰

Notice that here we have divided the head *v* into three heads: Init, Proc and Res (Ramchand 2008). This illustrates nicely the consequences in Nanosyntax of the claim that an abstract head can have one interpretable feature at most. The reason for decomposing the verb into these three heads is that the aspectual information associated with the event expressed by *go* consists of more than one interpretable property. When someone goes somewhere, we are expressing three subevents: there is a process whereby an entity moves (ProcessP, or ProcP); there is an initial phase where the entity initiates some movement presumably using its own locomotive capacity (InitiationP, or InitP), and if the event is completed, there is a result state where the entity is now in a different location (ResultP, or ResP). Second, notice that tense has also been divided into two heads: one that denotes tense in itself, as a deictic category that places the eventuality with respect to the utterance, and another one that specifically gives the past value to that deictic orientation, denoting that the event is placed before the utterance time.

If we now look to the case of *classified*, it becomes apparent that – in contrast to Distributed Morphology – the exponents that spell out the structure are not just introduced in the head position, as there are only three exponents for 6 heads. Nanosyntax claims that exponents typically correspond to phrasal constituents, that is, that what looks like a single morpheme on the surface corresponds to an in principle unbounded set of heads, as roughly represented in (27):

¹⁰ It is controversial whether roots, as category-less units, are allowed in Nanosyntax or not. Nothing in our exposition crucially depends on this fact.

However, the regular word would still be decomposed in a number of surface exponents. In contrast, an irregular form will be stored as a different unanalyzed exponent in the list: while the underlying structure of both verb classes could be identical, the difference emerges only at the level where the exponents have to be introduced.

To wrap up this section, here are the crucial points made by the authors discussed here, with the exception of Halle (1973), where there is no real division between regulars and irregulars.

- a. Words can have internal morphological structure; in fact, regular words are decomposed in morphemes
- b. Irregular words, involving substitution of segments and not addition of new morphemes, are listed as atoms.

2.4 Wrap up

In Table 1, we summarize the main properties of the theories discussed here, for them to be connected in a principled way with their potential psycholinguistic predictions. We summarize here our four criteria: (a) what is stored, (b) whether

storage uses one single list or several, (c) what is computed and (d) what kind of computation is proposed.

Table 1: Key features of discussed theoretical models.

	(a) What is stored?	(b) How many lists?	(c) What is computed?	(d) What kind of computation is relevant?
Distributed Morphology (Halle and Marantz 1993)	Syntactic heads and exponents that spell them out; no word is stored	At least two: one for morphosyntax and one for morphophonology	Both regular and irregular forms are computed by syntactic rules and can be decomposed morphologically	Spell out, including readjustment rules, following a non-trivial set of post-syntactic operations
A-morphous morphology (Anderson 1992)	Only words (no morphemes are stored)	Arguably two: the phonological and the grammatical side of a rule do not match one-to-one	Any form derived from another word	Rule-based: words are taken as their inputs and produce other words as their outputs
Distributed Connectionism (Rumelhardt and McClelland 1986)	Regular and irregular words	Only one	All word relations are expressed through non-symbolic association	Strength of connections between forms
Halle (1973)	Morphemes in the lexicon; actual words in the dictionary	Only one	All words	Combination of morphemes through word formation rules
Minimalist Morphology (Wunderlich 1992)	Morphemes and irregular words	Only one	Only regular forms	Affixation
Nanosyntax (Starke 2002)	Morphemes and irregular words	Arguably one: a list of exponents directly spelling out tree structures	Syntactically, both; morphologically, only regular forms	Insertion in (non-terminal) nodes

We now move on to an evaluation of how the psycholinguistic evidence supports some of these approaches, or at least some aspects of them, but before

doing so we will introduce the psycholinguistic research methods that are employed to investigate storage and computation of inflected words.

3 Psycholinguistic tools

The rationale behind psycholinguistic research is that a specific and established experimental effect is used to test the predictions derived from theoretical approaches. A number of different experimental effects such as the *frequency effect*, the *priming effect* or the *ungrammaticality effect* have been identified in psycholinguistic research over the last decades. The presence, absence, or strength of the tested effect in the experimental data is interpreted as evidence for or against a given theoretical model. Here we introduce the two most relevant experimental effects that have been used to explore representations and mechanisms involved in inflectional morphology: the frequency effect and the priming effect.

3.1 The frequency effect: The lexical-decision task as a window to lexical storage

An experimental effect that is used to establish whether an element of interest is stored in the mental lexicon is the frequency effect. The frequency effect is typically measured in a lexical-decision experiment.

To understand the meaning of a spoken or written word we have to build up a graphemic or phonetic representation that allows us to activate the word's entry in the mental lexicon. Activation of the lexical entry gives us access to the word's meaning. The frequency effect captures the observation that the more often we encounter a specific word, the quicker we are to activate the word's lexical entry, as memory traces get stronger with each exposure. The time we take to activate a lexical entry can be measured with a lexical-decision task where subjects have to decide as quickly and accurately as possible whether a presented item is an existing word or not by pressing a 'yes' or 'no' button on a keyboard. The reaction time required to carry out this word-nonword discrimination task is measured from the presentation of the item up to the pressing of the response button (see Figure 1 for an example of the set-up of a lexical-decision experiment). To test for a frequency effect, reaction times for frequently and infrequently occurring lexical units are compared. A frequency effect is stated if subjects take significantly less time to decide that frequent items (such as the

task: word/non-word decision

frequency effect:

example:	
frequent word:	Katze 'cat'
infrequent word:	Tatze 'paw'

reaction times for words in ms:

Figure 1: Frequency effect in a lexical-decision experiment.

German word *Katze* ‘cat’ in Figure 1) are existing words than they take for infrequent items (such as the phonologically similar word *Tatze* ‘paw’). In contrast, items not stored in the mental lexicon will not display a frequency effect in a lexical-decision experiment since there are no memory traces that could be influenced by frequency of activation. The frequency effect can thus be used as a diagnostic tool to investigate which entities are stored in the mental lexicon. While it is uncontroversial that roots and stems are stored in the mental lexicon and should hence be affected by frequency of activation, the issue whether inflected word forms or inflectional affixes are also stored in the mental lexicon is disputed both in theoretical and psycholinguistic research (cf. for instance Penke 2006).

Lexical-decision times are, however, not only influenced by how frequently we have encountered a specific element. Other factors, not related to frequency, will also influence reaction times and interfere with the frequency effect. Thus, reaction times to longer words (e.g. *crystallize*) are longer compared to shorter words (e.g. *cure*). Also the type of non-word displayed might influence reaction times. Non-words are presented to provide subjects with a meaningful task (word/non-word discrimination) ensuring that they actually read (or listen) to the stimuli presented. If, however, non-words only consist of unpronounceable letter strings (e.g. *cccc*), the word/non-word discrimination can be done on

visual characteristics of the stimuli alone, without the need to actually read the words. In this case reaction times to words might not reflect the time taken to activate a lexical entry. All factors that might potentially affect reaction times have to be carefully controlled in a lexical-decision experiment to ensure that it is only the frequency of occurrence of the tested lexical items that influence decision times (see Balota 1994; Cortese and Balota 2012 for a more thorough discussion of factors influencing visual word recognition).

3.2 The priming effect: Cross-modal priming yields evidence for morphological decomposition

The lexical-decision task can also be used to test for another effect important in psycholinguistic research: the priming effect. The priming effect captures the observation that subjects are quicker to respond to a word in a lexical-decision task if they have already encountered the very same word shortly before in the experiment. This priming of the target word by a prior presentation of this word (the prime) is most likely due to the fact that the activation threshold for the target's lexical entry is still lowered from the first activation of this lexical entry by the prime. This lexical entry can hence be activated more easily when the word is encountered again (cf. e.g. Balota 1994; Cortese and Balota 2012; Foster 1999).

In a priming experiment we compare two conditions, a primed and an unprimed condition that are typically distributed over two subject groups. Consider Figure 2 for explanation. In both subject groups the lexical-decision times for the target element (e.g. *chair*) are measured. For subject group A, this target word is primed since subjects have encountered this word before. This first presentation of the element is called the prime. In group B, in contrast, the target (e.g. *chair*) is not primed by a prior presentation of this word. A comparison of the lexical-decision times to the target element (e.g. *chair*) taken by the two subject groups will yield a priming effect, i.e. reaction times to the target will be significantly shorter in subject group A, for which the target has been primed, compared to reaction times of group B, for which the target has not been primed.

A number of different priming methodologies are employed in psycholinguistic research. The one that is considered most relevant for the issue of storage and computation in the mental lexicon is the cross-modal priming paradigm (cf. e.g. Marslen-Wilson 2007). In a cross-modal priming task the reaction times to a visually presented target word are evaluated in relation to an auditorily presented prime word. In the priming condition the auditorily presented prime word and the visually presented target word are identical. In the

Figure 2: The priming effect in a lexical-decision task (identity priming).

unprimed condition, the auditorily presented word is semantically, morphologically and phonologically unrelated to the visually presented target word (see Figure 3 for an example of the set-up of a cross-modal priming experiment). The cross-modal presentation of prime and target ensures that shorter reaction times in the primed condition are not due to the perception of surface visual or

task: word/non-word decision for the visual stimulus

Figure 3: Exemplary set-up for a cross-modal priming experiment.

sound similarities between prime and target, as would be possible if both elements were presented auditorily or visually. With a cross-modal presentation, we ensure that the priming effect is due to the activation of the lexical entry by prime and target word.

The priming effect can be used to investigate whether complex word forms are composed out of constituent morphemes. In morphological priming a morphologically related word such as *sings* is presented as prime for the target base form *sing*. Morphological priming is evaluated against an identity condition where prime (e.g. *sing*) and target (e.g. *sing*) are identical. The identity condition serves as a baseline to explore whether an inflected prime such as *sings* will prime a target *sing* as effectively as the word *sing* itself. The rationale behind the morphological priming effect is the following: When an inflected prime such as *sings* is encountered, it is decomposed into its constituent parts, the stem *sing-* and the affix *-s*. The stem then activates its entry in the mental lexicon. Due to this activation, the activation threshold for this entry is lowered. When the target *sing* is presented subsequently, the stem *sing* has already been activated before and its activation threshold has been lowered. The access to this stem's entry is now faster – a priming effect occurs. If, in contrast, inflected forms are not decomposed into stem and affix but are stored as whole word forms in the mental lexicon, the inflected prime (i.e. *sings*) will not be decomposed and hence, the stem's lexical entry will not be directly activated by the prime. Subsequent presentation of the target (i.e. *sing*) will then not lead to a priming effect comparable to the identity condition (prime *sing*, target *sing*), since the stem *sing* has not been directly activated by the inflected prime *sings* presented before. Thus, an inflected word form that is morphologically related to a target word will only fully prime this target if the inflected form is decomposed into its constituent morphemes. The priming effect is hence used to explore whether or not inflected word forms are decomposed into constituent morphemes.¹¹

¹¹ The same rationale applies to investigations focusing on the issue whether compounds or derived words are decomposed. As morphologically related words are generally similar in form (orthography or phonology) and meaning, experiments testing morphological priming have to make sure that the priming effect is not simply due to an overlap in form and/or meaning between prime and target. This can, for instance, be achieved by comparing morphological priming conditions to experimental conditions addressing overlap in form (e.g. prime *ring*, target *sing*) or in meaning (e.g. prime *tune*, target *sing*) (cf. e.g. Frost et al. 2000).

4 Psycholinguistic evidence

Let us now consider what the psycholinguistic evidence testing for storage or computation has to say regarding the discussed theoretical frameworks. Before starting, we would like to make some cautionary remarks. For one, it is not possible to discuss every relevant experiment that has been conducted in the field. Rather, our exposition will focus on showing what type of evidence can be used in principle in addressing the issue of storage and computation in the mental lexicon. Second, as already indicated above, all experimental research is in danger to be flawed by factors not sufficiently controlled in the experimental set-up (see Cutler 1981). As the field develops, factors that were not considered vital at the time the experiment was run might turn out to be important in the future, thus leading to a different evaluation of the experimental findings. Most research related to the issue of storage and computation of inflected forms has focused on the English past tense (cf. e.g. Pinker 1999 for an overview). English, however, is not ideally suited to investigate regular and irregular inflected forms. In English, regular inflected forms have an overt suffix (e.g. *-ed* in *laugh* – *laughed*, or *-s* in *chair* – *chairs*), whereas irregular inflected forms often only display a change of the stem vowel (e.g. *sing* – *sang*, *tooth* – *teeth*) and there are no endings that always appear on irregular inflected forms. Hence, the regularity or irregularity of inflected forms is confounded with the presence or absence of a separable inflectional ending in English. This confound might affect experimental research. For instance, due to the suffix, regular inflected forms are often longer than irregular inflected forms that only show stem changes. Also experiments making use of a different priming technique, i.e. masked priming, have found a very early, presumably prelexical effect in processing visually presented words in which potential affixes are stripped on the basis of morpho-orthographical cues alone (cf. Rastle and Davis 2008). Such an operation would apply to regular verbs but not to irregular verbs without a separable ending (e.g. *sang*) (but see Crepaldi, Rastle, Coltheart, and Nickels 2010). A difference between regular and irregular inflected forms that shows up in an experiment might, hence, be due to the presence of a separable ending rather than to the issue whether the inflection is regular or irregular. Given this potential confound, we will concentrate our exposition mainly on data from German – a language where irregular inflected forms have separable endings too and where the issue of storage and computation of inflected forms has been thoroughly investigated over the last 20 years (cf. Clahsen 1999; Penke 2006 for an overview).

4.1 Testing for storage

The frequency effect has been used to investigate which entities are stored in the mental lexicon. If an inflected form is stored in the mental lexicon, we should observe a frequency effect, i.e. reaction times to frequently occurring inflected word forms should be quicker compared to more infrequently occurring inflected word forms. As an example, consider a lexical-decision experiment that was investigating whether German past participle forms are stored in the mental lexicon (Clahsen, Eisenbeiss, and Sonnenstuhl 1997).

Regular inflected past participles are built with the suffix *-t* that is attached to the verb's base. Hence, regular inflected past participles do not show stem changes in the participle form, as in (29a) and (29b). In contrast, irregular inflected past participles often show a modification of the stem vowel in the participle form and take the ending */n/*, as in (29c).¹² Neither the stem vowel nor the phonological shape of the verb's base predict whether a verb is regularly or irregularly inflected. Consider for example the verbs *blinken* 'flash' and *trinken* 'drink': Whereas *trinken* in (29c) has the irregular participle form *getrunken*, the verb *blinken* in (29b) has the regular participle form *geblinkt*. The prefix *ge-* is phonologically conditioned and occurs on regular and irregular past participle forms.

(29)	<i>Infinitive</i>	<i>Participle</i>	<i>Gloss</i>
a.	tanz-en	ge-tanz-t	'dance'
b.	blink-en	ge-blink-t	'flash'
c.	trink-en	ge-trunk-en	'drink'

In their lexical-decision task Clahsen, Eisenbeiss, and Sonnenstuhl (1997) presented infrequently and frequently occurring German regular and irregular participles and measured how long it took their subjects to decide whether the presented participle was a German word or not. Consider two irregular participles such as *gegraben* (from the verb *graben* 'dig') and *geschlagen* (from the verb *schlagen* 'hit'). While the German CELEX corpus (Baayen, Piepenbrock, and van Rijn 1993) yields 34 occurrences of the participle *gegraben* in its database of 6 million words, the participle *geschlagen* is much more common and occurs 644 times in this corpus. If these irregular participle forms are stored in the mental lexicon, we should expect a frequency effect in lexical-decision times. Thus, it should take subjects longer to decide that *gegraben* is a German

¹² In spoken language the ending is usually only realized as */n/*. The ending is, however, written as <en>.

word compared to the more frequent *geschlagen*. Clahsen, Eisenbeiss, and Sonnenstuhl obtained lexical-decision times for 9 infrequent (mean participle frequency 81) and 9 frequent irregular participles (mean participle frequency 364) from 26 adult native speakers of German and found a clear and significant frequency effect for irregular inflected participles. Whereas their subjects took 652 ms (mean reaction time) to decide that an infrequent irregular participle was an existing word, the mean reaction time for frequent irregular participles was only 593 ms (see Figure 4, part a). This frequency effect indicates that irregular inflected participle forms are stored.

Figure 4: Lexical-decision times for regular and irregular German participles according to Clahsen, Eisenbeiss, and Sonnenstuhl (1997).

In the same experiment, Clahsen, Eisenbeiss, and Sonnenstuhl also tested lexical-decision times to 9 infrequent regular participles, such as *gepflanzt* 'plant' (frequency 27, mean frequency of 9 infrequent regular participles 78) and to 9 frequent regular participles such as *gespielt* 'play' (frequency 348, mean frequency of 9 frequent regular participles 379). If regular inflected participle forms are stored like irregular participle forms in the mental lexicon, we should observe a frequency effect, with longer lexical-decision times for infrequent regular participles compared to frequent ones. However, no such frequency effect occurred. The mean decision times for infrequent (613 ms) and frequent (617 ms) regular participles did not differ significantly, despite the fact that frequent and infrequent regular participles were matched in frequency to frequent and infrequent irregular participles (see Figure 4, part b). The lack of a frequency

effect for regular participles indicates that these regular inflected forms are not stored in the mental lexicon.

To ensure that differences between regular and irregular participle forms were only due to the regularity of the inflectional marking, Clahsen, Eisenbeiss, and Sonnenstuhl matched the participle forms in the regular and irregular condition for frequency and made sure that the chosen irregular participle forms did not show any ablaut in the verb stem and only differed with respect to their participle ending /t/ or /n/. A replication of this study made use of a slightly modified set of items also controlled for word length and the frequency of the verb's stem between regular and irregular participles. This study confirmed the findings of Clahsen, Eisenbeiss, and Sonnenstuhl for another group of 30 participants (Neubauer and Clahsen 2009). A frequency effect for irregular inflected forms and a lack of a frequency effect for matched regular inflected forms have also been observed for a different set of participle forms including irregular participles that have an ablauting participle stem (Clahsen, Eisenbeiss, and Sonnenstuhl 1997) and for German noun plurals that display a similar difference between regular and irregular forms (Penke and Krause 2002).

While the above mentioned studies compared lexical-decision times to regular and irregular inflected forms carefully matched to each other, a number of studies have focused on regular inflected forms only. Lexical-decision studies on highly inflecting languages such as Finnish have confirmed that regular inflected forms are associated with longer reaction-times compared to monomorphemic words matched in word length. This processing cost for regular inflected forms suggests that the form is decomposed into its constituent morphemes – a process that involves additional operations and hence more time compared to monomorphemic words (e.g. Laine Vainio, and Hyönä 1999; Lehtonen et al. 2007).

Studies focusing on the processing of regular inflected forms have identified a number of conditions and factors within an individual speaker or a given language and inflectional system that will lead an individual to store at least some regular inflected forms (e.g. Alegre and Gordon 1999; Bertram et al. 2000; Bertram, Schreuder, and Baayen 2000; Lehtonen and Laine 2003).

Consider for example language acquisition. From an acquisitional perspective, a number of regular inflected forms have to be stored by the child before she would be able to generalize a productive means to produce regular inflected forms from these stored forms (see e.g. Weyerts and Clahsen 1994; Penke 2006, 2012b). Even after a rule or affix entry for the regular inflection has been derived by the child, the once stored regular inflected forms might remain in the mental lexicon.

Also, it might be the case that accessing a frequently occurring stored form in the mental lexicon is quicker than decomposing this form into constituent morphemes before access (e.g. compare the reaction times for frequent regular (617 ms) and frequent irregular participles (593 ms) in the experiment described above).¹³ Thus, it might be advantageous to store those regular participle forms an individual often encounters. In fact, Alegre and Gordon (1999) observed a frequency effect within a group of frequently occurring regular English past tense forms, indicating that these very frequent regular forms are stored. For a group of regular past tense forms with a lower frequency of occurrence a frequency effect was, however, not observed by Alegre and Gordon, suggesting that less commonly occurring regular past tense forms are not stored (see also Lehtonen and Laine 2003 for similar findings on Finnish).

Bertram and colleagues have suggested affix homonymy as another factor that might lead to regular inflected forms being stored in the mental lexicon (Bertram et al. 2000; Bertram, Schreuder, and Baayen 2000). Based on investigations of homonymous affixes in Finnish and Dutch Bertram and colleagues suggested conditions under which regular inflected forms might be stored to speed-up performance. They, for instance, suggested that regular inflected forms are stored if homonymous affixes occur with comparable frequency (Bertram et al. 2000; Bertram, Schreuder, and Baayen 2000). Also, Baayen, Dijkstra, and Schreuder (1997) reported a frequency effect for nouns inflected with the Dutch regular plural suffix *-en*, but no frequency effect for verbs inflected with the verbal plural affix *-en* and suggested that regular inflected noun plurals might be stored because the noun affix *-en* occurs with considerable less frequency than the homonymous regular verbal suffix *-en*. Note, however, that this finding could not be replicated for German where a similar homonymy between a regular noun plural suffix *-en* and a regular verbal ending *-en* exists (Penke and Krause 2002), suggesting that the storage of homonymous regular inflected forms is dependent on language-specific factors.

Last but not least, gender and age of acquisition have also been suggested to influence storage of regular inflected forms (Ullman 2005). Neubauer and Clahsen (2009), for example, conducted a modified version of the Clahsen,

¹³ Note, however, that the reverse seems to hold for speech production. In a production experiment on English regular and irregular past tense forms Cohen-Shikora and Balota (2013) reported that the production of regular past tense forms was significantly faster than the production of irregular past tense forms matched for frequency, word length, phonological and orthographical complexity. Thus, it might be the case that advantages associated with storage or computation of inflected forms differ for speakers and hearers/readers.

Eisenbeiss, and Sonnenstuhl (1997) study presented above with a group of native German speakers and a group of advanced adult Polish learners of German. While their native German subjects displayed no frequency effect for the regular inflected participles, the results for the second-language learners of German showed a strong frequency effect for regular as well as irregular inflected participles. Based on these results Neubauer and Clahsen concluded that adult second-language learners rely more on memorization of inflected forms than native speakers. Ullman (2005) has suggested that the stronger reliance on memorization might be due to increasing levels of estrogen during adolescence that inhibit the procedural memory system subserving grammatical computations and enhance the declarative memory system that underlies the mental lexicon. Hence, second-language learners that start learning after a certain critical age as well as women for whom estrogen levels are higher than in men tend to store regular inflected forms instead of computing them.

As this short discussion has exemplified, the issue whether or not regular inflected forms are stored in the mental lexicon has led to a number of experimental studies that yielded divergent results with respect to frequency effects for regular inflected forms. Nevertheless, the following summary of the available literature is justified:

- a. Whereas studies have disputed whether and which regular inflected forms display frequency effects in lexical-decision experiments, the finding that such effects can reliably be found for irregular inflected forms is not controversial.
- b. Lexical-decision tasks where reaction-times for carefully matched regular and irregular inflected forms are directly compared quite consistently report different performance patterns for regular and irregular inflected forms: whereas irregular inflected forms yield a frequency effect, no frequency effect is observed for regular inflected forms, indicating that regular inflected forms are generally not stored as fully inflected forms.
- c. Studies focussing on regular inflected forms only, have identified certain factors that might nevertheless lead to the storage of regular inflected forms. These studies have provided important insights on how individual speakers organize their mental lexicon to cope with the requirements of speedy speech production and comprehension given the language they speak and the inflectional system at stake. However, one could argue that the aim of theoretical models as discussed above is a different one. The issue is not to highlight conditions under which it might be advantageous for an individual to store a regular inflected form given the time pressures of speech production and comprehension, but the aim is to provide a generalization of the representation of inflectional morphology that is valid

across languages, inflectional systems and individuals. To achieve this goal and to gain a deeper understanding of the principles governing the system under investigation morphological theories generally abstract away from individual findings and concrete experimental data, a procedure that has been advocated by Chomsky as the Galilean style of rational inquiry in linguistic research (e.g. Chomsky 2002; see Penke and Rosenbach 2007). Given this perspective of theoretical models, the currently available evidence suggests that, notwithstanding specific parsing requirements favoring storage of regular inflected forms under certain conditions, regular inflected forms do not have to be stored but are in general computed.

4.2 Testing for decomposition

The cross-modal priming paradigm has been used in psycholinguistic research to investigate whether regular and irregular inflected forms are decomposed and activate their constituent morphemes in the mental lexicon. Sonnenstuhl, Eisenbeiss, and Clahsen (1999) used the cross-modal priming paradigm to investigate the processing of regular and irregular inflected German participles. They compared lexical-decision times for regular inflected first person singular forms such as *plane* ‘plan’ in three conditions: (a) in the identity condition the target first person singular form (e.g. *plane*) was preceded by an identical verb form as prime (prime *plane*, target *plane*); (b) in the morphological condition the target first person singular form (e.g. *plane*) was preceded by a participle form as prime (prime *geplant* ‘planned’, target *plane*); and (c) in the control condition the target was preceded by a prime not phonologically, morphologically, or semantically related to the target (prime *öffne* ‘open’, target *plane*) (cf. Table 2, part A).

The rationale behind this experimental set-up is the following: when a subject encounters the regular inflected first person singular form (e.g. *plane*), this form is decomposed into the verb stem *plan* and the inflectional suffix *-e*. As the verb stem is identical to the verb’s base (e.g. *plan* ‘plan’), this base entry is activated. In the identity condition, the same regular inflected form is presented twice, as auditory prime and as visual target for lexical decision. By encountering the target, the form is again decomposed, and the verb’s base is activated. Since the base has already been activated by parsing the prime, subjects are now quicker to activate the base entry again and are hence quicker to decide that the presented target form (e.g. *plane*) is an existing German word, compared to the control condition where the target (e.g. *plane*) is not related to the prime (e.g. *öffne*). The identity condition is then used as a baseline to establish

whether a priming effect will also occur in the morphological test condition where subjects encounter a participle form such as *geplant* as prime before the target first person singular form (e.g. *plane*).

Table 2: Priming effects for regular and irregular inflected German participles according to Sonnenstuhl, Eisenbeiss, and Clahsen (1999).

A. Priming with regular inflected participles			
	(i) identity condition	(ii) morphological condition	(iii) control condition
prime (auditory)	<i>plane</i> ('plan _{1.sg.} ')	<i>geplant</i> ('planned.')	öffne ('open _{1.sg.} ')
target (visual)	<i>plane</i> ('plan _{1.sg.} ')	<i>plane</i> ('plan _{1.sg.} ')	<i>plane</i> ('plan _{1.sg.} ')
lexical-decision time for target	581 ms	581 ms	611 ms
☞ no significant difference in reaction-time between identity and morphological condition			
B. Priming with irregular inflected participles			
	(i) identity condition	(ii) morphological condition	(iii) control condition
prime (auditory)	<i>schlafe</i> ('sleep _{.sg.} ')	<i>geschlafen</i> ('slept.')	<i>beuge</i> ('bow _{.sg.} ')
target (visual)	<i>schlafe</i> ('sleep _{.sg.} ')	<i>schlafe</i> ('sleep _{.sg.} ')	<i>schlafe</i> ('sleep _{.sg.} ')
lexical-decision time for target	563 ms	595 ms	620 ms
☞ Significant difference in reaction-time between identity and morphological condition			

When subjects heard a regular inflected participle form such as *geplant* in the morphological condition, the mean reaction time for the target form (e.g. *plane*) (581 ms) was not different from the identity condition where the form *plane* was presented twice (581 ms) (cf. Table 2, part A). This observation indicates that a regular participle form such as *geplant* is as good a prime for the inflected form *plane* as is the form *plane* itself. The explanation for the observed morphological priming effect is the following: when a subject encounters a regular inflected participle such as *geplant* as prime, this form is decomposed into its constituent parts, the stem *plan* and the participle affix *-t*, during lexical access. As the stem *plan* is identical to the verb's base entry (e.g. *plan*), this base entry is activated in the mental lexicon. Due to this activation, the activation threshold for this entry is lowered. When the regularly

inflected form *plane* is presented subsequently as target for lexical decision, this form, too, is decomposed into the stem *plan* and the first person singular affix *-e*. The stem will then activate the verb's base entry (e.g. *plan*). Since this base entry has already been activated before by the prime word and since its activation threshold has therefore been lowered, the access to this base entry is now faster – a morphological priming effect occurs.

What if an irregular participle such as *geschlafen* ('slept') precedes its regular inflected first person singular form (e.g. *schlafe*)? In this case, the mean lexical-decision time for the target form (e.g. *schlafe*) (595 ms) is significantly longer compared to the identity condition where *schlafe* is presented twice (563 ms) (cf. Table 2, part B). This result shows that an irregular participle such as *geschlafen* does not prime the inflected form *schlafe* as effectively as a regular participle such as *geplant* primes the inflected form *plane*. Why not? Sonnenstuhl, Eisenbeiss, and Clahsen (1999) have suggested that irregular inflected participles such as *geschlafen* are not decomposed into stem and affix since they are stored as whole word forms in the mental lexicon. Thus, the presentation of the irregular participle *geschlafen* does not lead to a direct activation of the verb's base entry *schlaf*. When the regular inflected target form *schlafe* is subsequently presented as target, this form is decomposed into stem *schlaf* and affix *-e* and the verb's base entry *schlaf* is activated. However, since the base entry *schlaf* has not been directly activated by the participle prime presented before, there is no priming effect comparable to the identity condition where the form *schlafe* is presented as prime and target.¹⁴

Summarizing, the priming data from Sonnenstuhl, Eisenbeiss, and Clahsen (1999) suggest that irregular participles do not prime regular inflected forms as effectively as regular participles. The priming effect observed for regular participles indicates that regular inflected forms are decomposed into stem and affix constituents. The finding that irregular participles do not display a similar priming effect, in contrast, suggests that irregular inflected forms are not composed out of stem and affix, but are stored as whole word forms in the mental lexicon.

A critical issue in evaluating differential priming effects of regular and irregular inflected forms is whether differences in priming can be related to

¹⁴ Note, however, that compared to the control condition (620 ms) the morphological condition (595 ms) yields a partial priming effect. This partial priming can be accounted for by the assumption that irregular inflected forms are associated with the verb's base entry in the mental lexicon (see also Allen and Badecker 2002). Thus, although the irregular inflected form is not decomposed into stem and affix and is thus not able to directly activate the verb's base entry, it is nevertheless able to lower the activation threshold for the base entry via the associative connections between the inflected form and its base.

differences in regularity alone or whether items in the regular and irregular condition also differ with respect to other dimensions. Regular and irregular inflected forms may, for example, differ in how much they overlap in phonological form with the morphologically related target form. Thus a regular inflected English past tense form such as *walked* is more similar to a target *walk* than the irregular inflected form *taught* is to *teach*. However, the different morphological priming effects observed for regular and irregular inflected German participles by Sonnenstuhl, Eisenbeiss, and Clahsen (1999) cannot be explained by differences with respect to form or meaning overlap between regular and irregular inflected forms, by differences in word length, or by differences in the frequency distribution of the regular and irregular inflected participle forms. Specifically, regular and irregular inflected participles were equally similar to their base forms (*geschlafen* – *schlaf* vs. *geplant* – *plan*) because only irregular participles without stem changes were tested. Also differences between the regular and the irregular experimental condition cannot be due to differences in meaning overlap between the two conditions since the same inflected verb forms (first person singular forms and participles) were tested in the regular and the irregular conditions. Thus, Sonnenstuhl, Eisenbeiss, and Clahsen suggest that the difference in priming effects observed for regular and irregular inflected participles is related to the regularity of the inflectional marking alone.

Differential priming effects for regular and irregular inflected forms have been confirmed in cross-modal priming experiments across inflectional systems and languages. Sonnenstuhl, Eisenbeiss, and Clahsen (1999) confirmed their finding of full-priming with regularly inflected morphological primes and the lack of a full-priming effect with irregular inflected morphologically related primes in a second experiment, where they tested regular and irregular inflected German noun plurals (see also Sonnenstuhl and Huth 2002). A priming asymmetry with full-priming for regular inflected forms and partial or no priming for irregular inflected forms was also found in English where *walked* primes *walk* as effectively as *walk* primes *walk*, whereas *gave* will not prime *give* (cf. e.g. Marlsen-Wilson, Hare, and Older 1993; Stanners et al. 1979).¹⁵ A comparable priming asymmetry has also been reported for Greek (Tsapkini, Jarema, and Kehayia 2004).

In contrast, to the studies mentioned above, some studies have claimed a comparable facilitation in morphological priming conditions for regular and irregular inflected forms. Such differences in outcome might be related to

¹⁵ See Allen and Badecker (2002) for an explanation for why irregular inflected English past tense forms have been associated with partial priming or no priming in previous studies.

differences in experimental design. Thus, studies that do not include an identity condition, for instance, do not allow for identifying whether reported priming effects are full (i.e. comparable to identity priming) or partial (e.g. Feldman et al. 2010; Orsolini and Marslen-Wilson 1997; Smolka, Zwitserlood, and Rösler 2007). Also, different evaluations of what constitutes a regular or irregular inflected form will lead to different interpretations of the data. Feldman et al. (2010) for example refer to a study on French inflected verbs by Meunier and Marslen-Wilson (2004) as supporting their finding of a comparable priming effect for regular and irregular inflected forms. Indeed, Meunier and Marslen-Wilson found no difference between the four different French verb classes tested in their priming study, but they only tested forms inflected with regular affixes in all four verb classes. Hence, no differences with respect to decomposition were to be expected for these forms – as Meunier and Marslen-Wilson note themselves.

Summarizing, while controversies in the field focus on the issue whether irregular inflected forms do or do not display priming effects comparable to the effects observed for regular inflected forms, it is not disputed that regular inflected forms yield full morphological priming effects, indicating that these forms are decomposed into constituent morphemes.

4.3 Evaluating the evidence

Let us now evaluate how the morphological theories discussed in Section 3 fare vis-à-vis the evidence discussed. We will focus here on those findings that are relatively uncontroversial in the field of psycholinguistics.

4.3.1 Irregular inflected forms display frequency effects

It is uncontroversial in psycholinguistic research that irregular inflected forms display frequency effects in a lexical-decision task: reaction times to infrequent inflected forms are significantly longer compared to frequent inflected forms. Controversies focus on the issue whether regular inflected forms display frequency effects too.

As described above, the frequency effect observed for irregular inflected forms is evidence that these inflected forms are stored in the mental lexicon. Hence, all morphological theories that do not assume storage of irregular inflected forms would not be compatible with the available psycholinguistic evidence. This would be problematic for Distributed Morphology (see Section 3.1), that argues that

irregular inflected forms are computed through readjustment rules. Although the verb bases that undergo a specific readjustment rule have to be stored in the input conditions of this rule (see 17), the resulting irregular form is not stored, as there is a rule that derives it. Hence the observed frequency effects for irregular inflected forms cannot be straightforwardly explained in this framework. A frequency effect for irregular verbs might result from different frequencies of the readjustment rules necessary to derive irregular inflected forms, i.e. a less frequently applied rule might take more time for activation or computation compared to a more frequently applied readjustment rule. Note, however, that in the experiment of Clahsen, Eisenbeiss, and Sonnenstuhl (1997) described above all irregular participles had to undergo the same readjustment rule (30). When the same readjustment rule applies for all items in the irregular test condition, no frequency effect should occur according to Distributed Morphology, contrary to findings. This explanation of the observed frequency effect for irregular inflected forms can thus be ruled out.

- (30) /V/ --> /V/ / X__Yn [participle]
 For X = *√*grab, schlaf, lauf, . . .

Another potential explanation for a frequency effect in irregular inflected forms that would be compatible with Distributed Morphology is that such a frequency effect is not due to different frequencies of the inflected forms but to different frequencies of the base forms. Recall that it takes longer to activate a less frequently occurring base compared to a frequently occurring base. Base frequencies did, however, not differ between regular and irregular test conditions in the study of Clahsen, Eisenbeiss, and Sonnenstuhl-Henning (1997), and can thus not account for the observation that a frequency effect was only observed for irregular but not for regular forms. A similar critique can be made of Halle's (1973) model, to the extent that in his model all words, regularly or irregularly inflected, are computed at some level in the lexicon.

In contrast, the finding of a frequency effect for irregular inflected forms is compatible with all theories that assume that these forms are stored in the mental lexicon in one way or another: MM, A-morphous Morphology, Nanosyntax and Distributed Connectionist models.

4.3.2 Regular inflected forms are decomposed

The finding that regular inflected verbs display a full morphological priming effect is not disputed in psycholinguistic research either. Controversies concern the question whether similar priming effects can be obtained for irregular inflected

verbs. The observation that a regular inflected form such as *sings* primes a target *sing* as effectively as an uninflected prime *sing* suggests that regular inflected forms are decomposed into constituent morphemes (*sing*-, -s). On a principled view then, morphological accounts that assume that inflected forms are not decomposed into constituent morphemes (see Section 3.2.) are not compatible with this finding. This would, in principle, cause problems for Anderson's (1992) A-morphous Morphology and for Distributed Connectionist models.

Is it possible to reconcile these accounts with the available experimental evidence? With respect to A-morphous Morphology much of the answer hinges on the issue how a hearer or reader would parse a regular inflected form according to this theory, which is in fact formulated from a speaker's perspective. Can an inflectional rule be reversed so that the base can be derived from the inflected form, in practice undoing the job that the rule does? If so, the fact that the base is primed by the inflected regular form might not in itself be a counter-argument to Anderson's (1992) proposal.

A priming effect might also be reconciled with connectionist approaches and result from the phonological overlap between inflected form (*sings*) and base (*sing*). Note, however, that in the priming experiment by Sonnenstuhl, Eisenbeiss, and Clahsen (1999) described above the amount of phonological overlap was controlled for regular and irregular inflected forms (compare regular *geplant* – *plane* and irregular *geschlafen* – *schlafe*). Despite a similar phonological overlap between inflected forms and base forms in regular and irregular inflected forms, a full priming effect was only observed for the regular inflected forms. This renders it unlikely that a priming effect can be based on phonological overlap alone, which is a problem for connectionist approaches.

The finding should also be problematic for Halle's (1973) account. Halle proposes that word forms are stored in the dictionary while the word formation component would only be put to use when encountering an unfamiliar word or when using an invented word. Hence, regular and irregular inflected forms would be equally stored in the dictionary according to his proposal and could be parsed and understood without recourse to the word formation component. A full priming effect for existing regular inflected forms that is indicative of morphological decomposition would thus not be predicted by Halle's account.

The finding that regular inflected forms are decomposed into constituent morphemes is, however, fully compatible with those approaches that assume that regular inflected forms are composed out of constituent morphemes, i.e. Distributed Morphology, MM and Nanosyntax.

4.3.3 Regular and irregular inflected forms are different

A consistent finding of experiments that have directly compared the reactions to carefully controlled regular and irregular inflected forms is that regular and irregular inflected forms are associated with different performance patterns in these experiments. In the experiments described above regular and irregular inflected forms differ with respect to frequency effects as well as with respect to priming effects. This would be hard to reconcile with theoretical approaches that do not assume differences between regular and irregular inflected forms with respect to storage or computation, specifically Distributed Morphology, where all forms are computed, and Distributed Connectionist models, as well as Halle's (1973) theory, where all words are or can be stored.

At a closer look, however, things are not as easy. While Distributed Morphology assumes that all inflected forms are computed in the morphosyntactic component, regular and irregular inflected forms do differ as only the latter undergo a readjustment rule – a difference that in principle could account for different performance patterns in psycholinguistic experiments. In connectionist models, different performance patterns between regular and irregular inflected forms might be based on differences in the input data the network receives and computes. Thus, for instance in English past tense inflection, regular inflected forms by far outnumber irregular inflected forms with regard to type and token frequency, i.e. the number of regular inflected verbs as well as the frequency of their past tense forms by far exceed those of irregular inflected verbs (cf. Clahsen 1999 for discussion). While this difference might underlie the different performance pattern observed in psycholinguistic testings on English regular and irregular morphology (cf. e.g. Gonnerman, Seidenberg, and Andersen 2007), the frequency distribution of regular and irregular inflected forms (participles and noun plurals) is different in German, where, for instance, the regular -s Plural is in fact quite infrequent (cf. Clahsen 1999). Despite differences in the frequency distribution of regular and irregular inflected forms in English and German, psycholinguistic experiments have yielded comparable findings, for instance with respect to morphological priming (e.g. Stanners et al. 1979; Marlsen-Wilson, Hare, and Older 1993). This observation casts doubt on the assumption that differences between regular and irregular inflected forms can solely be based on differences in the frequency distributions of regular and irregular forms.

It would seem that the finding of different performance patterns for regular and irregular inflected forms would be particularly problematic for Halle's (1973) account. Recall that Halle's theory cross-cuts the distinction between regular and irregular inflected forms. Regular and irregular inflected forms familiar to

an individual will be stored in the dictionary, else they will be derived by word formation rules. While a regular or irregular inflected form might be stored or derived by rule, there is no principled difference between the operations and representations involved in regular and irregular inflected forms in his account. How different performance patterns could result from the processing of regular and irregular inflected forms matched for frequency and hence (un)familiarity for the experimental subjects remains a challenge for this account.

The different performance patterns associated with regular and irregular inflected forms might also pose a challenge to separationist theories such as Distributed Morphology and Nanosyntax, which assume that regular and irregular inflected forms have the same representation at the morphosyntactic level and only differ at spell out. While one could argue that the different performance patterns observed in psycholinguistic experiments originate at the morphophonological level, where regular and irregular inflected forms differ according to separationist theories, we cannot at this point exclude the possibility that the tested effects address the morphosyntactic level, where both types of inflected forms display the same type of representation. To clarify this issue, experimental effects have to be found that selectively target morphosyntactic and morphophonological representations.

In contrast to the discussed theories, Minimalist Morphology – a unitarist theory that draws a distinction between regular and irregular inflected forms in terms of computation – and A-morphous Morphology (where there are rules relating regular forms, but irregulars are stored) are compatible with the evidence regarding different performance patterns for regular and irregular inflected forms.

4.3.4 Controversial findings

In contrast to the three findings discussed above, the following two findings are debated in psycholinguistic research, as discussed in Sections 4.1 and 4.2:

- a. Regular inflected forms do not show a frequency effect.
- b. Irregular inflected forms do not show full priming.

Most studies that have directly compared regular and irregular inflected forms conclude that regular inflected forms are not subject to frequency effects, whereas irregular inflected forms are. The lack of a frequency effect for regular inflected forms can be interpreted as these forms not being stored. This finding would run against models where regular forms are stored, i.e. connectionist models and Halle's (1973) model, which assumes that the dictionary stores

familiar regular forms. Also, priming experiments have shown that irregular inflected forms do not prime their base as effectively as regular inflected forms, suggesting that irregular forms are not subject to decomposition, and thus that they are not computed by aggregation of different pieces. This finding might go against the proposal in Distributed Morphology, where irregulars are derived through readjustment rules. Note, however, that the absence of an effect in a given experiment does not provide strong evidence that the effect is absent on principled grounds. The inability to find an effect might also be due to the experimenter's inability to find the effect. Thus, for instance large variances in the data might prohibit finding a statistically significant difference in reaction times to frequent and infrequent regular inflected forms. Carefully chosen stimuli as well as replications of the experimental results across subject groups, inflectional systems and languages would, of course, strengthen the assumption that the lack to find an effect is not an accident. With respect to the evaluation of the discussed morphological theories there is, however, no need to rely on these two negative findings, as they provide no new evidence regarding the discussed morphological theories.

The following Table 3 summarizes how each one of the theories discussed here fares with respect to the experimental results according to our assessment.

Table 3: Summary of the psycholinguistic evaluation of the discussed theoretical models.

finding compatible with	Irregulars display frequency effect (thus, are stored)	Regulars are decomposed (thus, they are computed)	Distinct nature of regulars and irregulars (thus, both cannot be stored, both cannot be computed)
Distributed Morphology	No	Yes	Perhaps
A-morphous Morphology	Yes	Perhaps	Perhaps
Distributed Connectionism	Yes	No	No
Halle (1973)	No	No	No
MM	Yes	Yes	Yes
Nanosyntax	Yes	Yes	Perhaps

The conclusion is that out of the theories discussed here, those that seem to fit better with the available psycholinguistic evidence are, in our opinion, MM and Nanosyntax, and possibly A-morphous Morphology.

5 Conclusions

To conclude, in this chapter we have reviewed which aspects of morphology are computed and stored in a number of different theories that we believe are representative of different theoretical standpoints in the field. We have confronted the predictions of these theories to the currently available experimental psycholinguistic evidence, in an attempt to connect two sides of the debate that tend not to be combined. From this overview, several conclusions can be drawn.

An interesting outcome of this overview is that the theories that we think fare better with respect to the psycholinguistic evidence cut across the two dimensions that arguably are the most prominent ones in theoretical debates: (i) lexicalism vs. neo-constructionism and (ii) Item-and-Arrangement vs. Item-and-Process. Two of them are lexicalist theories (MM and A-morphous Morphology), while the third is neo-constructionist (Nanosyntax); one of them is clearly Item-and-Process (A-morphous Morphology) while the other two argue that morphemes are segmentable units (MM and Nanosyntax). This fact is not trivial and suggests to us that the debate about storage vs. computation is deeper and has more consequences than the other two analytical oppositions just mentioned.

Second, we have also seen that not all theories allow for psycholinguistic tests to the same extent. Specifically, approaches with a grounded notion of morpheme as a unitary object make clearer predictions with respect to priming and frequency effects than separationist approaches where morphophonological aspects are in principle independent of the abstract morphosyntactic representation. Testability is presumably a legitimate factor to evaluate theories, and this would imply that a theory like MM is in principle better suited than, for instance, Nanosyntax to set the grounds for a more stable collaboration between psycholinguists and theoretical morphologists. However, psycholinguistic techniques, making fine-grained distinctions between morphophonology and morphosyntax, might be developed in order to test the more fine-grained predictions of separationist theories. Another issue is whether a theory allows for explicit predictions regarding the processing of inflected words by a hearer or reader. As morphological theories are typically designed from a speaker's perspective, such predictions are not always easily derived and – as in the case of Item-and-Process theories – require some principled thoughts on the reversibility of morphological rules.

Finally, several properties have emerged that have to be met by a morphological theory in order to be compatible with the experimental evidence about storage vs. computation. In such a theory, regular and irregular morphology must be treated differently in a principled matter, with evidence strongly suggesting that the first is computed while the second is stored. Presumably, the dictionary component, if there is any in the theory, cannot simply be a place

where complex words are listed as soon as they are learned. That theory has to be explicit with respect to what the allowed computational operations are and what the limits are of what can be stored.

There are many open issues still, but we hope that in writing this chapter we have encouraged other scholars to consider seriously how psycholinguistics and theoretical morphology can collaborate in order to produce an account of storage and computation that is both theoretically sound and compatible with the experimental evidence available.

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