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The lexical-syntactic representation of number

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Number is an important aspect of lexical syntax. While there has been substantial research devoted to number agreement at the level of the sentence, relatively less attention has been paid to the representation of number at the level of individual lexical items. In this paper, we propose a representational framework for the lexical syntax of number in spoken word production that we believe can account for much of the data regarding number in noun and noun phrase production. This framework considers the representation of regular and irregular nouns, and more unusual cases such as *pluralia tantum* (e.g. scissors), zero plurals (e.g. sheep) and mass nouns (e.g. garlic). We not only address bare noun production but also the production of determiner + noun phrases. While focusing on examples from English, we extend the framework to include languages with grammatical gender such as German.

Keywords: language production; lemma; lexical-syntactic features; number; mass nouns

Speaking involves the conversion of ideas and concepts into spoken word forms. In many languages, words that belong together syntactically have to agree on certain language-specific grammatical attributes. These attributes are called lexical-syntactic features or properties. Caramazza (1997) made a distinction between *intrinsic* and *extrinsic* syntactic features, while Levelt, Roelofs, and Meyer (1999) refer to the same distinction using the terms *fixed syntactic properties* and *variable syntactic features*. Intrinsic, fixed syntactic properties are lexical features that belong to words in an idiosyncratic way, i.e., there are no conceptual cues as to what the feature value may be. An example of an intrinsic syntactic property is grammatical gender (e.g. masculine, feminine, neuter). In Dutch noun phrases, the form of the determiner and the inflectional suffix of an adjective have to agree in gender with the noun referent. For instance, *de arm* (the_{com} arm_{com}) vs. *het been* (the_{neu} leg_{neu}) or *lange arm* ($long_{com}$ arm_{com}) vs. *lang been* ($long_{neu}$ leg_{neu}). Note that there is no conceptual reason for arm (*arm*) to have common gender in Dutch, while leg (*been*) has neuter gender. In other words, the gender values of Dutch nouns are idiosyncratic; there is no transparent semantic or phonological relationship or rule. However, in many Romance languages, for instance, there are phonological cues to the gender value of nouns. In Spanish, for example, words ending in -a are generally feminine. Nevertheless, as there are exceptions to this phonological rule, e.g. *el poeta* (the_{mas} $poet_{mas}$), it can still be maintained that even in these languages, grammatical gender is an intrinsic feature.

In contrast, extrinsic, variable syntactic features are not word-specific and have a conceptual basis. Examples of extrinsic syntactic features include case (e.g. nominative, accusative, genitive, dative, etc.) and number. Number is used to control noun phrase agreement and subject/verb agreement in verb phrases. In English noun phrases, the determiner has to agree in number with the noun (e.g. *some apples* vs. *an apple*, *this apple* vs. *these apples*), and in other languages, adjectives also have to agree in number with the noun (e.g. German: *grüner Apfel* 'green apple' vs. *grüne Äpfel* 'green apples'). Similarly in verb phrases, the subject has to agree in number with the verb – if the subject is singular, the verb must be singular, if it is plural, a plural verb is required (e.g. *The boy runs* vs. *The boys run*). In other words, number is a syntactic feature, the value of which is set to singular or plural, depending on the conceptual context.

In this review, we focus on the representation of the extrinsic, variable lexical-syntactic attribute number. However, in our discussion, we will also refer to literature on other syntactic features as required, such as grammatical gender. Our aim is to propose a plausible architecture for number representation in word production which can serve as the basis for further experimentation.

Representation of grammatical information in models of speech production

Levelt et al. (1999) described what has become one of the best-known theories of word production. In this theory, concepts activate lexical-syntactic nodes (so-called

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lemmas), which eventually activate word forms. A lemma is in fact an empty node, pointing to two main kinds of information: syntactic diacritics representing lexical-syntactic attributes and the (phonological) word form. For instance, the lemmas for the German words *Löffel* (spoon), *Gabel* (fork), and *Messer* (knife) would all point to the syntactic word class diacritic NOUN, but *Löffel* would also point to the MASCULINE gender diacritic, *Gabel* to the FEMININE gender diacritic and *Messer* to the NEUTER gender diacritic. In the case of these intrinsic, fixed, syntactic attributes, activation of the diacritics occurs solely from the lemma node. However, as noted above, some (extrinsic, variable) syntactic attributes, like number, also depend on conceptual input for their value.

In this review, we focus initially on count nouns where number is represented as singular and plural, but then move on to consider less common items such as *pluralia tantum* (scissors, pants) and mass nouns (water, garlic). We aim to generate a model of number processing which can account for current data in the literature, including data relevant to both bare noun production ("cat", "beans") and noun phrase production ("a cat", "some beans"). While the origin of the model is Levelt et al. (1999), as will become apparent, we find it necessary to diverge from this in several ways.

Figure 1 represents Levelt et al.'s depiction of the representation of most plurals. In this model, the syntactic diacritic for plural receives input from conceptual nodes as well as from the noun lemma. Seeing many cats will activate not only the concept CAT but also a concept which relates to the fact that there is more than one – Levelt et al. (1999) label this concept MULTIPLE. The concept nodes for CAT and for MULTIPLE send activation to the lemma level: CAT activates the lemma *cat* (the same lemma as is activated when naming a single cat), and the conceptual node MULTIPLE activates a plural diacritic at the lemma level. Levelt et al. state that the lemma with its plural feature then activates the two morpheme nodes for the stem and plural affix <cat> and <s>.

Unfortunately, it is difficult to determine how this could work in practice, given the sketch of the architecture – how does activation of the plural diacritic result in the lemma *cat* activating the morpheme <cat> and the plural affix, rather than just the morpheme <cat> alone, as it would for a singular? There seem two logical ways we might circumvent this issue: the first (Figure 2) is that plural diacritics directly activate plural affixes. Levelt et al. assume that all nouns share a single plural diacritic which seems the logically most economical representation. However, the result is that whenever the concept MULTIPLE is activated, this plural diacritic will be activated, and consequently, plural affixes will also be activated. In this case, when producing a word with an irregular plural (e.g. mouse), this would erroneously receive affixation resulting in regularisation ('mouses' or perhaps 'mices'). Consequently, this account would require a mechanism to prevent such errors for irregular plurals. Indeed, such mechanisms have been proposed in 'blocking and retrieval' models (e.g. Marcus et al., 1992). In these models, regular forms are formed by a default rule, 'add *-s* to form the plural'. Irregular forms are retrieved from the mental lexicon as full forms and block the application of the default regular rule. However, here, we

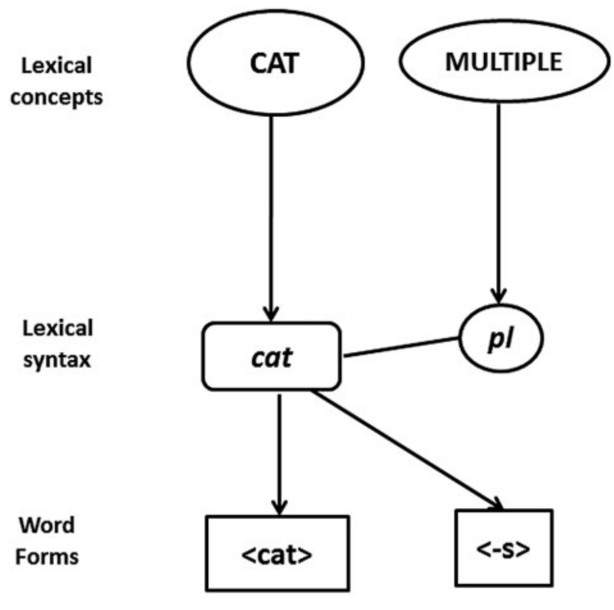

Figure 1. Levelt et al.'s representation of plurals (adapted from Levelt et al., 1999, p. 13, Figure 7b).

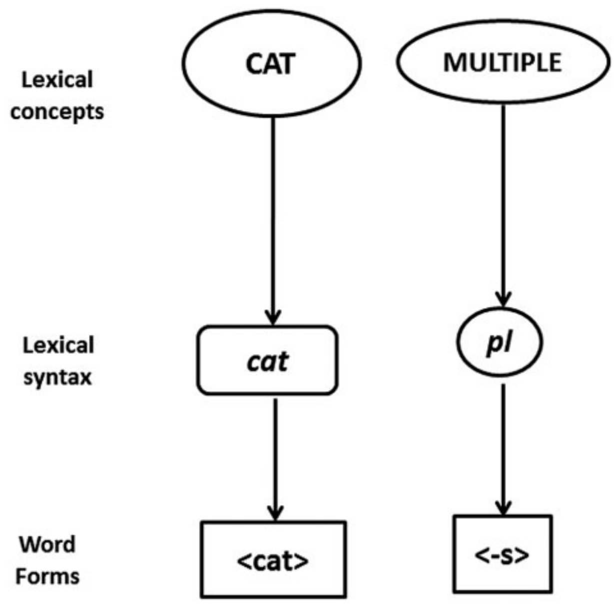

Figure 2. An architecture where plural lemmas directly activate plural affixes.

propose an alternative possibility, where this problem is solved by the concepts for nouns being linked to separate lemmas for singular and plural (Figure 3a). Before we continue further, we should note a number of aspects of this model which are beyond the scope of this review, given our focus on the lexical-syntactic representation of number. In order to sketch the model's architecture, we must choose to depict representations at each level in a certain way. However, in each of the cases listed below, nothing rests on this choice in terms of the claims we make and we appreciate that the basic architecture could be implemented in different ways. For example, we have chosen to depict concepts as single nodes, but we remain agnostic regarding whether these representations in fact consist of semantic features (e.g., Dell, 1986; Dell, Schwartz, Martin, Saffran, & Gagnon, 1997) or a holistic representation of meaning with labelled links indicating the relationships between concepts (e.g., Levelt et al., 1999). Similarly, we have chosen to use unidirectional arrows, but are sympathetic to models which assume (restricted) interaction between levels (e.g. Goldrick & Rapp, 2002; Rapp & Goldrick, 2000).

We represent lemmas as converging on a single morphological stem at the word form level but do not intend to enter the debate regarding the nature of word form representation (morphological representation). Some theories suggest that each lemma activates its own separate word form (as is necessarily the case for irregular plurals), while others suggest that lemmas which share phonology may converge on a single word form. Here, we choose the latter option which is supported by data on homophones (Biedermann & Nickels, 2008a, 2008b; Dell, 1990; Jescheniak & Levelt, 1994; Jescheniak, Roelofs, & Meyer, 2003). For example, Biedermann and Nickels (2008a, 2008b) demonstrate that improved retrieval of one homophone following treatment (e.g. *flower*) shows generalisation to improved production of its partner (e.g. *flour*; for arguments against a single representation for homophones, see, for example, Caramazza, Costa, Miozzo, & Bi, 2001; Miozzo & Caramazza, 2005).

In addition, some authors suggest that regular morphological forms, such as regular plurals, are stored decomposed at the word form level (e.g., Clahsen, 1999; Levelt et al., 1999; Pinker, 1999), while others suggest that they are stored as full forms (e.g. Butterworth, 1983). A third group of authors argue that both decomposition and full form processing occur, with high frequency regularly inflected words being likely to be stored as full forms while their low frequency counterparts may be stored decomposed (e.g. Bybee, 1985; Stemberger & MacWhinney, 1986). While we favour the latter view, for convenience, we depict all regular plurals as being stored decomposed at the phonological word form level, and do not debate this in detail (but see Biedermann, Beyersmann, Mason, & Nickels, 2013 for further discussion).

Finally, we assume, for English, that singulars are uninflected. This position is supported by some experimental data. For example, Berent, Pinker, Tzelgov, Bibi, and Goldfarb (2005) conducted a task where Hebrew[1] speakers had to say how many words there were on the screen while ignoring what the words were. They found a number congruency effect for the singular but not for the plural, in general: saying "one" was slowed if that word was plural (e.g. 'cats') rather than singular (e.g. 'cat') or a neutral letter string ('mmm'), but this was not true for saying 'two' to singular nouns (e.g. 'cat cat') which did not differ from a neutral letter string condition ('mmm mmm'). However, other authors (e.g. Janssen, Roelofs, & Levelt, 2004) suggest that rather than having no inflection, singulars may in fact have 'null' affixes. This would also be compatible with our account, although we have chosen not to depict this (predominantly on the grounds of simplicity). Indeed, it could be argued that, to be cross-linguistically plausible, any theory must be able to incorporate inflections for both singular and plural. For example, Serbian inflects for number, case, and gender, thus, the masculine word 'potato' ($krompir_{masc\ sing\ nominative}$) is *krompiru* in the locative singular and *krompirima* in the locative plural (Mirković & MacDonald, 2013). Alternatively, it may be the case that languages differ in this respect: those languages where singulars are also inflected, like Serbian, will require singular affixes at the word form level, whereas those, like English, where singulars have no overt inflections, do not. Clearly, further research is required to distinguish between the two possibilities for English (null affix or no affix for singulars).

Returning to Figure 3a, a number of representational decisions immediately become apparent. First, we suggest independent lemmas for singular and plural forms, with a single concept activating both lemmas. We implement this as a possible solution for the 'overgeneralisation' problem that arises when a plural node directly activates a plural affix, as discussed above. However, it is possible for speakers to correctly inflect nonwords (e.g. one wug, two … [wugs]; Berko, 1958). Therefore, we retain the direct activation of plural lemma diacritics by the concept MULTIPLE suggested originally by Levelt et al. (1999), but propose that activation is generally weak (Figure 3b). This activation would not usually be sufficient to generate production of the plural affix when there is activation of the lexical concept of a noun. However, for nonwords, when no lexical concept is activated, the activation of the plural lemma diacritic will be sufficient to result in affixation of the nonword.

While it does not appear parsimonious to have two lemmas for the same noun, a number of authors have suggested this form of representation. Indeed, while Levelt et al. (1999) argue that most nouns have the representation shown in Figure 1 (earlier), they also suggest that some nouns do have independent lemmas

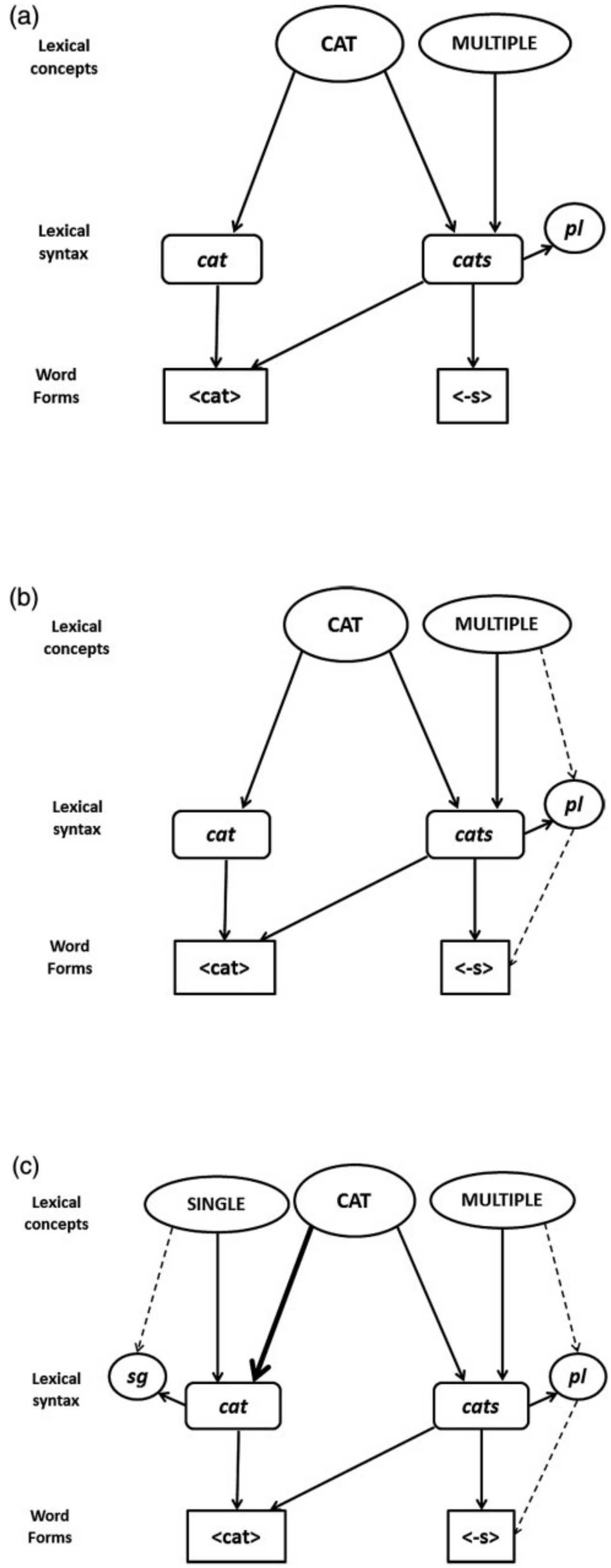

Figure 3. (a) Lexical-syntactic representation of regular plurals: implementing separate lemmas for singular and plural forms of a noun. (b) Lexical-syntactic Representation of regular plurals: implementing direct activation of plural diacritics to enable plural formation for nonwords. (c) Lexical-syntactic representation of regular plurals: implementing SINGLE conceptual feature nodes and a 'singular as default' mechanism using weighted connections from noun concepts to noun lemmas.

for singular and plural. They propose separate lemmas for the singular and plural of *plural dominant* nouns – those nouns where the plural is more frequent than the singular (e.g. beans, eyes). However, as Baayen, Levelt, Schreuder, and Ernestus (2008) put it, "this approach raises the question how plural-dominant a noun would have to be for it to be assigned a second lemma" (p. 25). Baayen, Dijkstra, and Schreuder (1997) used a mathematical model to simulate the effects of plural dominance on lexical decision in Dutch. The best fit of their data was found in a model where all plurals (independent of their dominance status) had their own lemma representations.

Levelt et al. also propose separate concepts for the singular and plural forms of plural dominant nouns, arguing that there is a conceptual difference between these items: "The word 'eyes' is not just the plural of 'eye', there is also some kind of meaning difference: 'eyes' has the stronger connotation of 'gaze'" (p. 13). While we do not rule out this possibility, if this is the case, it does perhaps suggest that plural dominant words are in fact more similar to polysemous words with different but related meanings (e.g. 'wood' which can mean both a piece of a tree and an area with many trees). Even if this is the case for (some) plural dominant nouns, we believe that, in general, singular and plural forms share a concept. Baayen, Lieber, and Schreuder (1997, p. 868) provide support for this stance, explicitly arguing that pluralisation affects the meaning of the singular noun by adding information on number but does not change it (but see Baayen et al., 1997).

Given that the same concept activates the lemmas for both singular and plural forms, how then is the appropriate form selected? The primary mechanism is through the activation of concept nodes relating to SINGLE or MULTIPLE entities depending, for example, on whether the speaker wishes to describe a single cat or many cats (Figure 3c). If the MULTIPLE node is activated, then this will provide additional activation to the plural lemma form *cats*. The combination of activation from the concept MULTIPLE and the concept CAT results in the plural lemma *cats* being more active than the singular *cat*. In contrast, if a single cat is to be described, the SINGLE concept node will be activated and the singular lemma *cat* will be the most active. In some languages, a grammatical distinction is made not just between singular (one of an object) and plural, but also includes grammatical marking of nouns when referring to duals (two of a referent; e.g. Arabic) and trials (three of a referent, e.g. Tolomako). In these languages, lexical-concept nodes would be hypothesised for SINGLE, DUAL, TRIAL and MULTIPLE. Other languages grammatically mark 'paucal' number referring to an imprecise but small number of items (e.g. Hopi, Arabic for some nouns; Corbett, 2000); these languages would be hypothesised to also have a PAUCAL node. Paucal equates to 'few' in English, and indeed, while it is not grammatically marked in English, there may nevertheless be a PAUCAL conceptual node which would activate the determiner 'few' (see below). Bock and Middleton (2011) note that there is a perceptual basis for the conceptual and grammatical coding of number that lies in our perceptual capacity to automatically enumerate between one and three objects. With more than three objects, judgments of number depend on counting, although judgments of relative quantity still occur automatically in terms of approximate magnitudes (Hyde & Spelke, 2009). In other words, conceptual encoding of whether there is one, two, three, few or multiple is an automatic consequence of our perceptual processing.

We have suggested explicit coding for both SINGLE and MULTIPLE at the concept level and *singular* and *plural* at the lemma level. However, a number of authors have suggested that singulars should be unmarked. For example, Schriefers, Jescheniak, and Hantsch (2002) assume that singular is the default, based on evidence from picture naming of single and multiple objects with noun phrases. They found that when singular and plural determiners were different (e.g., *der Tisch* 'the table' (sing. masc.) vs. *die Tische* 'the tables' (pl. masc.)), naming latencies were slower for plural noun phrases, suggesting that the singular form is activated 'by default' even when it is not required. Structural linguists have long considered the singular as the unmarked form and the plural as the marked form, and it is generally assumed that unmarked linguistic values have no overt expression (e.g. Greenberg, 1966; Tiersma, 1982). How can we reconcile this with the model shown in Figure 3c? We would interpret 'unmarked' or 'default' to indicate that in the absence of other input, the singular will be the easiest to retrieve. We have argued that conceptual coding of number (SINGLE/MULTIPLE) is a natural consequence of our perceptual system, and below we will suggest that for determiner production, a *singular* lemma diacritic is also desirable. Hence, we have chosen to implement the 'singular-as-default' hypothesis (Schriefers et al., 2002) as a stronger connection between the noun concept (CAT) and the singular noun lemma (*cat*) than between the concept and plural lemma (*cats*). This is indicated in Figure 3c by a thicker line. This weighting will result in greater activation for the singular lemma which, in a competitive system, will consequently be selected more quickly, leading to a processing advantage.

There are, however, situations where singular may not be the default, as in the case of plural dominant nouns – nouns where the plural is more frequent than its singular (e.g. beans, eyes). Plural dominant nouns have been found to behave differently from singular dominant nouns in a number of experimental paradigms (e.g. lexical decision: Baayen et al., 1997; picture naming: Baayen et al. 2008; Biedermann et al., 2013). The vast majority of these experiments find that while for singular dominant nouns, plurals are produced more slowly, the same is not true of

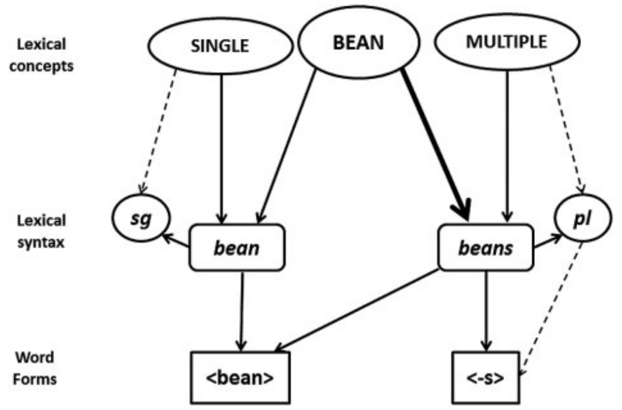

Figure 4. Lexical-syntactic representation of plural dominant nouns: using weighted connections from noun concepts to noun lemmas.

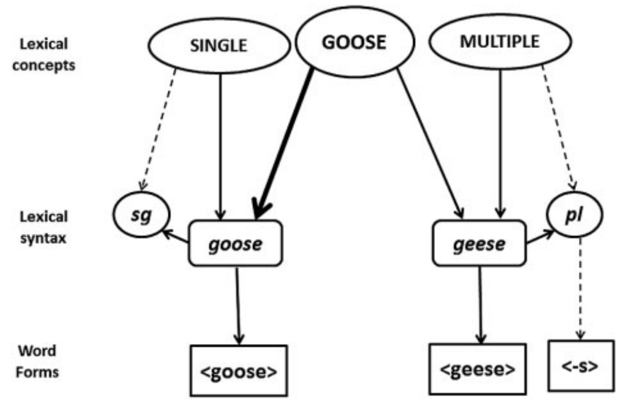

Figure 5. Representation of irregular plural forms.

plural dominants: For plural dominant nouns, there is little or no plural decrement. In one of only two studies to examine picture naming, Biedermann et al. (2013) demonstrated this pattern for both normal speakers and people with aphasia. The focus of the debate in this domain has been on the representation at word form level, particularly in those studies that have used a visual lexical decision task. However, on the basis of Baayen et al.'s (2008) results, Levelt et al. (1999) argued for differences in representation between singular and plural dominant nouns at a lemma and conceptual level. Biedermann et al. explicitly reject this account, as their data did not show the overall processing disadvantage for plural dominant nouns that was found in Baayen et al. (2008).

Here, we suggest that plural dominant nouns have the same conceptual and lexical-syntactic (lemma) representation as singular dominant nouns but different weightings between concept and lemma nodes.[2] This equates to what Tiersma (1982) describes as a markedness shift for plural dominant nouns (see Figure 4). Spalek and Schriefers (2005) propose a similar account to interpret the modulation of effects of determiner competition in picture naming by dominance. They suggest "the empirical data can be explained […] by assuming underlying activation patterns that reflect the relative dominance of the different morphological forms of a noun (p. 117)". We suggest that dominance effects in word production can be accounted for by the combination of the different activation patterns caused by weightings on concept-lemma links and effects deriving from word form level representation (perhaps both decomposed and full form representation for plural dominant plurals (e.g. <bean> + <s>, and <beans>); see Biedermann et al. (2013) for further discussion).

Irregular plurals

Figure 3c (earlier) depicts the representation of a regularly inflected noun where both singular and plural activate a single stem at the word form level. However, some plurals are irregular. We propose, in a move that is neither novel nor controversial, that concepts like GOOSE must not only have two separate lemma entries for singular and plural, but also two separate word form representations <goose> and <geese> (Figure 5). The concept GOOSE activates the lemma for both *goose* and *geese*. As the singular is more frequent than the plural, *goose* will usually receive more activation than *geese* from the concept level. In addition, if the to-be-expressed concept relates to a single goose, the *goose* lemma will receive activation from the SINGLE conceptual feature node. However, if the speaker intends to refer to more than one goose, the conceptual feature node MULTIPLE is also activated. The concepts for both GOOSE and MULTIPLE combine to activate the lemma *geese*, which in turn activates the word form <geese>.

As discussed above, adults rarely regularise irregular plurals, leading to our rejection of Figure 2 as a plausible architecture for the lexical syntax of number. However, not only can adults (and children from about the age of 5) produce plurals for nonwords (Berko, 1958), young children do produce regularisations (*mouses*) and over-regularisations (*mices*, e.g. Marcus, 1995). Similarly, people with aphasia also produce errors where they inflect irregular forms or mass nouns. For example, in picture naming, FME, a woman with aphasia (Biedermann, Lorenz, Beyersmann, & Nickels, 2012) said "two feets", "two toasts", and "moneys". Consequently, we suggest that when the to-be-expressed concept concerns multiple entities (e.g. more than one foot), there is (weak) activation of the regular plural suffix (via the *plural* lemma). This provides the mechanism by which such overregularisations may occur. Pinker (1998, p. 240) describes this process in slightly different terms "regular forms are default operations applying whenever memory retrieval fails to provide an inflected form".

Another form of irregularity in English plurals is to be found in those nouns that have identical singular and

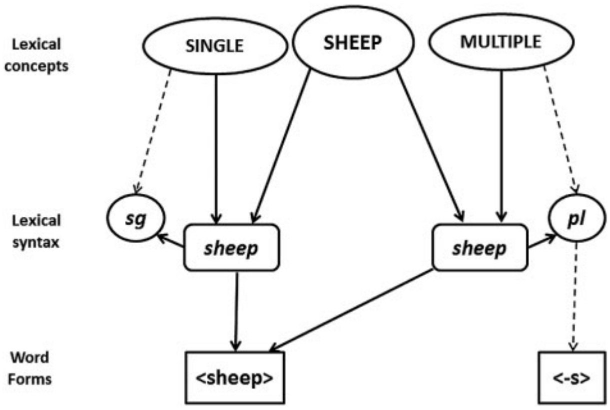

Figure 6. Representation of zero plurals.

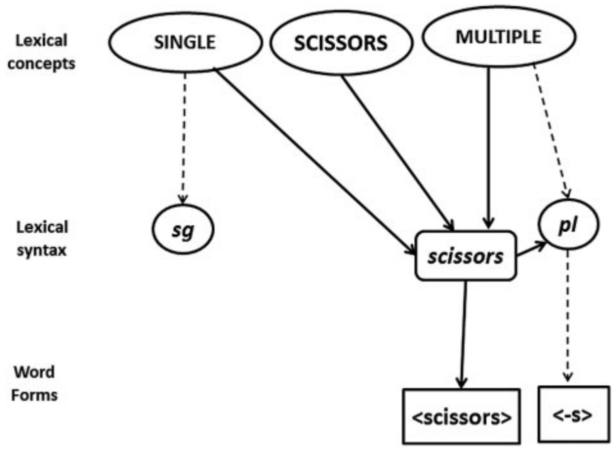

Figure 7. Representation of pluralia tantum.

plural forms (e.g. *sheep*, *fish*, also called *zero plurals*; Bock & Miller, 1991). Despite having no overt plural marking, these words still require number to be marked both conceptually (with the MULTIPLE node) and grammatically (with the plural diacritic), so that agreement processes between noun and determiner (*a sheep*, *some sheep*) or noun and verb (*the sheep is*… vs. *the sheep are*…) can operate (see Figure 6). In order to construct agreement, the processor has to have access to a plural feature linked to the lexical entry *sheep*. This can only be achieved by assuming a similar representation to that of regular plurals. Once again, these items may be vulnerable to overregularisation, when lexical activation is compromised. The critical issue here, however, is how the weak activation of the plural affix is insufficient to trigger production here (and for other irregular plurals) but sufficient to be produced for inflection of nonwords. We discuss this in the 'Challenges and Future Directions' section below.

When conceptual number and grammatical number diverge

Eberhard, Cutting, and Bock (2005) suggest four distinctions to assist in the understanding of number and number agreement: *notional* number, *grammatical* number, *morphological* number, and *noun subcategorisation*.

Notional number is often referred to as *conceptual* number and refers to the speaker's perspective on the numerosity of the intended referent. A noun's conceptual number, therefore, corresponds to whether its referent is one entity or multiple entities. Its grammatical number corresponds to whether it is grammatically singular or plural, and refers to its agreement properties. Confusingly (at least for those of us who view 'semantic' and 'conceptual' as virtual synonyms), grammatical number is sometimes referred to as semantic number (e.g. Berent et al., 2005). Grammatical number is frequently, but not always, reflected in the noun's morphological form – its morphological number. Morphological number refers to the morphological signals of plural number – plural inflections on nouns and verbs (e.g. plural 's' in English).

In the figures above, conceptual number is represented by the concept nodes SINGLE and MULTIPLE and grammatical number by the lexical-syntactic diacritics (*singular* and *plural*). In general, conceptual number and grammatical number converge – single entities are singular (one cat) and multiple entities are plural (three cats). However, this is not always true. Consider, for example, 'scissors'. Even though, when given a picture of a single pair of scissors, speakers construe this as a single entity (Bock, Eberhard, Cutting, Meyer, & Schriefers, 2001), the word 'scissors' is grammatically plural. That is 'scissors' requires a plural determiner and verb (e.g. "My only scissors are blunt"). *Scissors* is an example of a class of words sometimes known as *pluralia tantum* (e.g. pliers, goggles, trousers, etc.). These words are morphologically and grammatically plural whilst conceptually singular. These, then, require (yet) another variant of representation (see Figure 7). While the concept SCISSORS can conceptually refer to a single or multiple entity, it is never grammatically singular. Consequently, at the lexical-semantic level, there is only a single lemma corresponding to the plural *scissors* whether or not a single or multiple entity is intended by the speaker.[3] When a single pair of scissors is present, both the concept SCISSORS and the concept SINGLE will activate the lemma *scissors* with its associated plural diacritic enabling plural morphology. When multiple pairs of scissors are present, the concept MULTIPLE will activate the (same) *scissors* lemma.

Mass nouns

The representation of mass nouns has been a subject of debate for many years (Fieder, Nickels, & Biedermann, submitted a). There have been conflicting opinions regarding whether the status of a noun as mass (e.g.

Table 1. Comparison of grammatical and conceptual properties of mass and count nouns.

Count nouns	Mass nouns
Grammatical properties	
• Can be pluralised e.g. cats, lemons	• Cannot be pluralised e.g. *milks, *golds
• Can take indefinite or definite articles e.g. 'a cat', 'the cat'	• Restricted to the definite article (or no article) e.g. 'the sand', 'sand', but not *'a sand'
• Can take numerals e.g. 'one cat'	• Can take numerals only when preceded by a unit of measurement e.g. 'two kilos of sand', 'three piles of sand', but not *'two sands'
• Take quantifiers that denumerate e.g. 'many cats', 'few cats', but not *'much cat'	• Take quantifiers which do not denumerate e.g. 'much milk', 'little milk', but not *'many milks'
Conceptual properties	
• Entities with clear boundaries, indivisible or atomic (can be sorted and counted)	• Entities with no definite boundaries, non-atomic, unbounded substances and aggregates
• Perceived as individual entities	• Not perceived as individual entities
• Interact more as a single element	• Interact more as multiple elements

milk, gold) or count (e.g. cats, baskets) is determined on the basis of conceptual or grammatical attributes (see Table 1 for a summary). Nevertheless, it is clear that mass/count status (countability) has grammatical implications and therefore requires lexical-syntactic coding. However, some have argued that countability is predictable from conceptual properties (e.g. Iwasaki, Vinson, & Vigliocco, 2010; Langacker, 1987; Middleton, 2008; Middleton, Wisniewski, Trindel, & Imai, 2004; Wierzbicka, 1988; Wisniewski, Lamb & Middleton, 2003) and would therefore be an extrinsic syntactic feature set according to conceptual features. The problem is that while many, if not most, count nouns share the properties listed in Table 1, there are exceptions. Consider the pairs onion and garlic, pebbles and gravel, lentils and rice, peas and corn, (green) beans and asparagus. Conceptually, each member of the pair is very similar, yet one is count and the other mass, one requires plural grammatical agreement and the other singular. This seems strong evidence that countability status cannot be derived on-line from the conceptual representation of the noun, but rather is stored as an intrinsic lexical-syntactic attribute. In Figure 8, we have represented this as a diacritic *mass* at the lemma level. In the same way that 'scissors' was represented by a single lemma at the lexical syntax level, as *pluralia tantum* can only ever be grammatically plural, mass nouns are represented by a single lemma, as they are only ever grammatically singular.

Given that mass nouns are grammatically singular, in so far as they take singular verb inflections, why then do we suggest a *mass* lemma diacritic, rather than a singular diacritic? The major motivation is that mass nouns do not necessarily take singular determiners. For example, legal mass noun phrases cannot be formed with the singular determiner 'a' (**a garlic*), but can with the

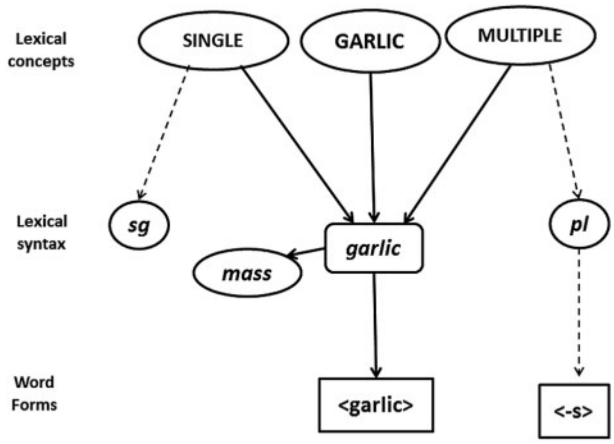

Figure 8. Representation of mass nouns

plural determiners 'some', 'enough' (*some garlic*, *enough garlic*). Critically, however, the reverse is also true, mass nouns can take the singular determiner 'this', but not the plural determiner 'those' (*this garlic*, **those garlic*). Moreover, there are determiners that are specific to mass nouns, such as 'much' (*not much garlic*, **not much onions*). Consequently, in order to consider this further, we must extend our discussion from bare nouns to noun phrases.

Number and noun phrase agreement

Thus far, our discussion of the representation of number has focused on the production of nouns in isolation. However, unless reciting a shopping list, nouns are far more often produced in phrases and sentences, and this is where the importance of number comes to the fore.

We restrict ourselves to consideration of agreement within a noun phrase, and predominantly between

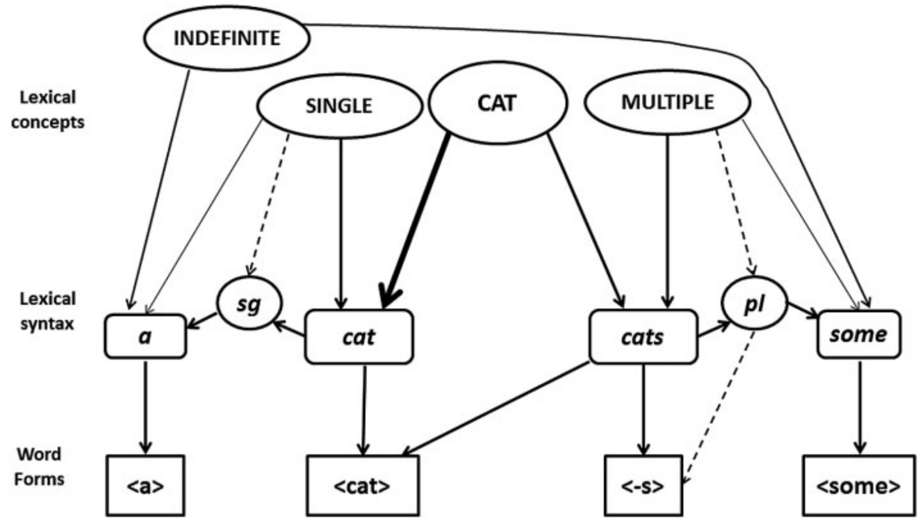

Figure 9. Integrating determiners into the model

determiners and nouns. Number agreement at the sentence level has been studied widely, see, in particular the work of Bock and colleagues (e.g. Bock et al., 2001; Eberhard et al., 2005; more recent examples include Bock, Carreiras, & Meseguer, 2012; Bock & Middleton, 2011; Mirković & MacDonald, 2013). However, there has been surprisingly little discussion in the literature regarding the representation and processing of determiners with a focus on grammatical number. Such research that there is comes from the picture-word interference literature. The bulk of the research in this literature examines the effect of lexical-syntactic congruency of superimposed written distractors on speed of noun phrase production in response to a picture. We will discuss this evidence below.

Figure 9 integrates determiner lemma nodes into the model for count nouns with regular plurals in English (Figure 3c, earlier). Each determiner lemma (*some, a*) is primarily activated by the corresponding number diacritic (*singular, plural*). However, in addition, determiner lemmas must be activated by conceptual nodes referring to their specific properties. Here, we have suggested an INDEFINITE concept node which would activate *some* and *a*, which would be distinguished from a DEFINITE node (not depicted) which would activate *the*. Other possibilities could include other aspects of quantification: for example, A LARGE QUANTITY, mapping onto “much” or “many”, or A SMALL QUANTITY mapping onto “little” or “few” (the concept PAUCAL, referred to above), and SUFFICIENT mapping onto “enough”.

We have also included direct mappings from the nodes SINGLE and MULTIPLE to determiners. This may seem redundant, given that number congruent determiners are activated via the noun lemma and its number diacritics (*singular, plural*). However, direct mappings are consistent with the general premise that determiners may be activated by concepts, as is necessary, for example, for selection of indefinite rather than definite articles. Moreover, Fieder, Nickels, Biedermann, and Best (submitted) provide evidence for an influence of conceptual representation on determiner selection in RAP, a man with aphasia. RAP had a lexical-syntactic impairment and his production of determiners in noun phrases was particularly impaired for mass nouns. In a series of experiments, Fieder et al. demonstrated that the number of depicted mass nouns influenced the accuracy of determiner production (e.g. *3 bulbs of garlic* or *1 bulb of garlic*). When the mass noun determiner was the same as the plural noun determiner (e.g. ‘some’), RAP produced more determiners correctly when more than one entity was depicted (e.g. *3 bulbs of garlic*, *3 jars of honey*). Conversely, when the determiners were also those used with singular count nouns (e.g. ‘this’), RAP’s determiner production with mass nouns was better when only one entity was depicted (e.g. *a single bulb of garlic* or *a single jar of honey*) than with multiple entities. This suggests that the congruency between perceived (conceptual) number information and the grammatical number of the determiner was important, and supports direct activation of determiners by conceptual nodes representing number (i.e. SINGLE and MULTIPLE nodes).

Further evidence for conceptual influences on determiner selection arises from investigations of another lexical-syntactic attribute – grammatical gender. Schiller, Münte, Horemans, and Jansma (2003) showed that gender decisions in German could be influenced by the biological sex (natural gender) of a noun referent. When there was congruency between biological sex and grammatical gender (e.g. *die Frau* (the$_{fem}$ woman$_{fem}$), *der Mann* (the$_{masc}$ man$_{masc}$)), grammatical gender decisions were faster than when words did not have biological sex

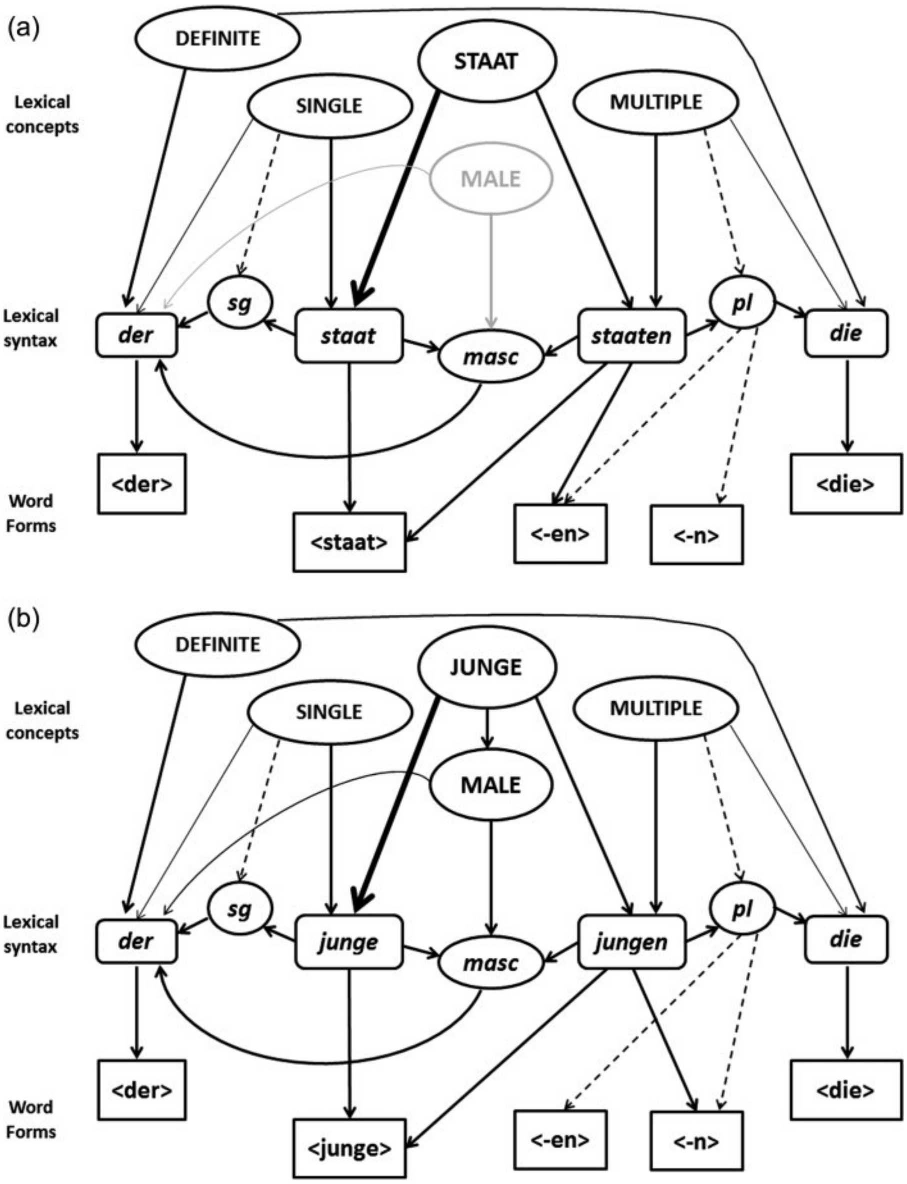

Figure 10. (a) An example from German, illustrating how grammatical gender can be integrated into the theory. (b) An example from German, illustrating how grammatical gender and natural gender can converge.

(e.g. *die Gabel* (the$_{fem}$ fork$_{fem}$), *der Tisch* (the$_{masc}$ table$_{masc}$)). This suggests that even grammatical gender may receive input from the conceptual level, at least in cases where there is biological sex. Work on Dutch diminutives further supports this position (see e.g. Janssen & Caramazza, 2003; Schiller & Caramazza, 2006; Spalek & Schriefers, 2005).

We would suggest, therefore, that there is clear evidence that conceptual number can influence grammatical number within the noun phrase, in just the same way that Bock and colleagues have demonstrated these influences within the sentence (e.g. Bock et al., 2001, 2012; Bock & Middleton, 2011; Eberhard et al., 2005).

Beyond English

In many ways, English is a very poor language in which to examine lexical syntax, given that it lacks grammatical gender, and case is not marked in the noun phrase. Consequently, in Figure 10, we give an example from German, where in addition to number, gender is also relevant to the selection of the appropriate determiner. Consequently, determiner lemmas receive activation from gender and number diacritics at the lemma level, and from natural gender (where it is a property of the to-be-expressed concept, Figure 10b) and number at the conceptual level. For example, the lemma for the singular definite determiner *der* can be activated via both the *singular* and the *masculine* lexical-syntactic diacritics and directly by the concepts SINGLE, DEFINITE and MALE.

In Figure 10a, we give the example of *Staat* (state or country) which is grammatically masculine, but is not conceptually masculine. Hence, the determiner and gender node receive no activation from the natural gender concept MALE. In contrast, in Figure 10b, *Junge* (boy) is an example of a noun which is grammatically and conceptually masculine. Hence, when referring to a single boy, the lemma for the singular definite determiner *der* is activated via both the *masculine* lexical-syntactic diacritics and by the concept MALE.

The plural determiner, *die*, is also the singular definite determiner for feminine nouns. Hence, there is the question of whether die_{plural} and $die_{fem,\ sing.}$ share a lemma node or have separate nodes. This question is more complex than it might first appear. On the one hand, as the two determiners differ conceptually (in number), it might seem appropriate to have independent lemma nodes (as we do for nouns). However, there is data from the picture-word interference task which suggest that perhaps, determiners share a lemma: there is no evidence of competition between a target noun of one gender and a distractor noun of a different gender when plural and singular determiners are the same (e.g. German *die*) (Costa, Kovacic, Fedorenko, & Caramazza, 2003; Schiller & Caramazza, 2003).

For German, case (nominative, accusative, genitive, etc.) also influences determiner selection. However, this is more complex than gender and number, as, in addition to conceptual factors, it may also involve interactions with sentence level syntactic processes. To avoid even further (visual) complexity, we have chosen not to depict 'case' in Figure 10. Similarly, for all languages, there will be lexical-syntactic nodes for word class, with corresponding conceptual input. For example, the lexical-syntactic attribute *noun* could be activated by a concept ENTITY or OBJECT, while *verb* might be activated by EVENT. In each case, the lemma corresponding to the concept (e.g. *cat*) would also activate the lexical-syntactic diacritic for word class (*noun)*. Once again, as these word class diacritics do not play a role in bare noun or noun phrase production, we have chosen not to depict them here. Clearly, however, they play a vital role in sentence planning and production.

Finally, the German plural system is considerably more complex than that of English and raises many questions of representation. For example, while the -s plural is generally considered the regular form, it only appears in 4% of types (2% of tokens; Sonnenstuhl & Huth, 2002). The most frequent plural inflection is -n/ -en (48% types; 45% tokens;) The simple -n ending can be considered predictable in the context of 'feminine' nouns that end in schwa. The next most frequent inflection is -e occurring in (27% types; 21% tokens) and then zero marking (17% types; 29% tokens). The experimental literature does not clarify the situation. For example, Marcus, Brinkmann, Clahsen, Wiese, and Pinker (1995) found that the -s plural was the preferred form (in acceptability judgements of inflected nonwords) only for nonwords that were perceived as borrowings, names or had unusual sounding roots. Kauschke, Kurth, and Domahs (2011) reviewed the language acquisition literature and report that typically developing children's over-applications (the equivalent of regularisation or overregularisation in English) in spontaneous speech predominantly involved the -n plural, even with older children (up to 9 years old). Interestingly, elicitation studies show a more variable pattern with -s and -e overapplications being more common. What are the implications of this complexity for the representation of German plurals in spoken word production? First, we need to be aware that it is hard to extrapolate from studies of input (e.g. acceptability judgements) to production since the morphological processes required are rather different. For example, the fact that listeners may find particular plural affixes acceptable when presented with them does not necessarily equate to them being represented as affixes and/or being productive in output.

In production, we would propose that despite the greater complexity of the German features, the same basic features would be shared as in the English plural system: Irregular plural forms would be stored as full forms, and predictable forms (e.g. Bett/Betten; Junge/Jungen) stored decomposed with links from the plural lemma to the stem and affix. However, it may be that German allows more than one different affix (e.g. -n, -en, -s, -e) whereas English has only one. Hence in Figure 10 (earlier) we include plural affixes for both –n and –en (but do not mean to imply that these are necessarily the only affixes). Furthermore, some German plurals involve a stem change in addition to an affix (e.g. Zahn -> Zähne). It is possible that they could be represented with full (uninflected) forms for singular and plural (e.g. Zahn; Zähne). Alternatively, the plural may be represented decomposed but, nevertheless, with a different stem to the singular (e.g. Zähn and -e). Only experimental investigation can inform this question.

The level of competition in noun phrase production

Thus far, we have concentrated on sketching the architecture of a model of noun phrase production with a focus on lexical syntax and its interface with concepts. However, it is also important to consider processing assumptions. We have made explicit that we conceive of the arrows in our sketches as weighted connections between representations, with thicker arrows representing stronger connections by means of higher weights. We also believe, in common with most theories of spoken word production, that there is a selection mechanism at the lexical-syntactic level (e.g.

Dell, 1986; Levelt et al., 1999) whereby the most active lemma is selected. In line with our focus on lexical syntax, we remain silent on whether word form representations are activated with a cascade of activation before selection of the lemma (e.g., Dell, 1986; Goldrick & Rapp, 2002), or whether this only occurs following lemma selection (e.g., Levelt et al., 1999). We do, however, propose that there is competition for lemma selection, as assumed by many authors (e.g. Harley, 1993; Levelt et al., 1999; Stemberger, 1985; for an alternative view, see e.g. Dell et al., 1997; Rapp & Goldrick, 2000). Competition is supported experimentally by, for example, semantic inhibition in picture-word interference tasks (e.g. Glaser & Düngelhoff, 1984) and cumulative semantic inhibition in picture naming (e.g. Howard, Nickels, Coltheart & Cole-Virtue, 2006). In the picture-word interference task, naming a picture (e.g., cat) is slowed when there is a semantically related superimposed distractor word (e.g., dog). While this has generally been taken as evidence of competition for selection between semantically related items (e.g., Roelofs, 1992; Starreveld & La Heij, 1996), there has recently been debate regarding whether a different account might apply – the response exclusion hypothesis (Finkbeiner & Caramazza, 2006; Janssen, Schirm, Mahon, & Caramazza, 2008; Mahon, Costa, Peterson, Vargas & Caramazza, 2007; see Roelofs, Piai, & Schriefers, 2013 for discussion). However, the cumulative semantic inhibition paradigm (e.g. Howard et al., 2006) involves a simpler task: sequential picture naming with embedded sets of semantically related items (e.g. farm animals, crockery). Here, there is also semantic inhibition (later items in a category are slowed relative to earlier items), but the response exclusion hypothesis cannot account for these data, as there is no alternative response to exclude (although alternative accounts to competition have been suggested nevertheless, e.g., Navarrete, Mahon, & Caramazza, 2010; Oppenheim, Dell, & Schwartz, 2010).

We will discuss competition in the context of the architecture we have sketched, while being aware that there may be alternatives. While several theories implement competition, the mechanism varies. For example, Levelt et al. (1999); Roelofs (1992) use the Luce ratio where selection probability of a lemma is affected by the activation of other lemmas. In contrast, Stemberger (1985) implements competition with inhibition between nodes. Once again, we have no data which speaks to which implementation is preferable, and leave this question open. We suggest, however, that due to the nature of conceptual activation, lemmas relating to a particular word class (noun, verb) will compete within that class. These lemmas will be those semantically related to each other (as these are the lemmas that are co-activated by lexical concepts), and for count nouns, the singular and plural forms will also be part of the network of competing lemmas. Hence, errors that occur as a result of competition at this level will tend to maintain word class and be semantically related (e.g. Dell, 1986; Dell et al., 1997).

We have briefly described the discussions around the need for competition for lexical selection at the lemma level in the production of single words. However, the question that has received most recent attention for noun phrase production is the level at which competition occurs: Is there competition between lexical-syntactic diacritics, determiner lemmas, or word forms? Much of the research here has focused on grammatical gender, rather than number, but is nevertheless relevant to the issue of competition at the lexical-syntactic level.

Schriefers (1993) used the picture-word interference paradigm to compare the effects on noun phrase production of distractor words which were of the same gender as the to-be-named picture (gender congruent) and those that were of a different gender (gender incongruent). He found that Dutch participants were faster to produce noun phrases such as *de rode stoel* (the$_{\text{common}}$ red$_{\text{common}}$ chair$_{\text{common}}$) as a response to a picture of a red chair when the visually presented distractor word agreed in gender with the target noun (e.g. *arm* 'arm$_{\text{common}}$') compared to when this was not the case (e.g. *been* 'leg$_{\text{neuter}}$'). Schriefers accounted for this gender congruency effect in the framework of Levelt et al.'s model assuming, as we have, lexical entries (lemmas) and corresponding syntactic features. Schriefers suggested that selection of the syntactic features (gender nodes) was competitive. Specifically, he proposed that in the gender-incongruent condition, target (*stoel*$_{\text{common}}$) and distractor (*been*$_{\text{neuter}}$) activate different grammatical gender nodes (*common; neuter*), which compete for selection, while this is not the case in the gender-congruent case where target and distractor converge on the same gender node.

This research has led to a proliferation of studies using both the picture-word interference paradigm (e.g. Alario, Ayora, Costa, & Melinger, 2008; La Heij, Mak, Sander & Willeboordse, 1998; Miozzo & Caramazza, 1999; Schiller & Caramazza, 2002, 2003) and a simple picture naming paradigm with no distractors (e.g. Alario & Caramazza, 2002; Schriefers et al., 2002). In Germanic and Slavic languages, these studies replicated Schriefers findings of a robust gender congruency effect in word picture interference tasks with noun phrase production (e.g. Bordag & Pechmann, 2009; Costa et al., 2003; Schiller & Caramazza, 2003; Schriefers, 1993). However, in Romance languages, there is little evidence for gender congruency effects (e.g. Alario & Caramazza, 2002; Costa, Sebastian-Galles, Miozzo, & Caramazza, 1999; Miozzo & Caramazza, 1999; Miozzo, Costa, & Caramazza, 2002). There is also no evidence for gender congruency effects when determiner forms are the same across genders (e.g. in the plural for German: *die*$_{\textit{feminine singular}}$ *Gabel* (the fork), *die*$_{\textit{plural}}$ *Gabeln* (the forks); masculine: *der*$_{\textit{masc sing}}$ *Löffel* (the spoon), die_{plural} *Löffel* (the spoons); neuter: $das_{neutersing}$ *Messer* (the knife), die_{plural} *Messer* (the knives); Costa et al., 2003; Schiller & Caramazza, 2003). There is also usually a lack of any gender congruency effect for bare noun retrieval (the noun alone, not in a noun phrase) in word picture interference with noun distractors (e.g. La Heij et al., 1998), but yet facilitatory effects of gender congruency have been found on bare noun retrieval with determiner distractors (Alario et al., 2008).

Far less attention has been paid to the effects of number congruency on noun phrase production. Schiller and Caramazza (2002) were the first to explicitly investigate effects of number congruency in picture-word interference. They demonstrated that for number, as for gender, there was no effect of congruency on bare noun naming. However, in stark contrast to the effect of gender, Schiller and Caramazza (2003) also found no congruency effect for number in noun phrase production, a result replicated by Fieder, Nickels and Biedermann (submitted b). Nevertheless, Schiller and Caramazza (2003) found that plural noun phrases were produced significantly faster than singular noun phrases, whereas for bare nouns, plural and singular were equally fast. This suggests that there is an influence of number on noun phrase production, but that it may be different to the effect of gender. This may relate to the fact that while gender is an intrinsic syntactic feature, number is extrinsic, and therefore, there is an early conceptual cue to noun phrase number which does not occur for gender.

Despite the substantial research effort devoted to the issue of competition in noun phrase production in general (but not with respect to number in particular), there is still debate regarding the nature and level of competition. While Schriefers (1993) argued for competition between syntactic diacritics, other authors suggested that competition between determiners was a more plausible source of interference either at the level of determiner form (see e.g. Miozzo & Caramazza, 1999; Schiller & Caramazza, 2002, 2003) or determiner lemma (e.g. Schriefers et al., 2002), while some authors argue for a non-competitive process (e.g., Alario et al., 2008). Jescheniak, Schriefers, and Lemhöfer (2012a, footnote 2) conclude "In fact, despite the somewhat weak empirical basis, it seems to be consensus among researchers in the field that the gender-congruency effect reflects interference in the gender-incongruent condition, with the only questions being of (1) whether this competition occurs at an abstract lexical (lemma) level or a word form level and (2) whether it is confined to free morphemes or not." Janssen, Schiller and Alario (in press) dispute this conclusion, noting inconsistent patterns in the critical gender x number interaction in the picture naming task stating "In short, this evidence undermines Jescheniak et al.'s conclusion that the data from the SPN [simple picture naming] task allow a consistent interpretation in terms of a competitive selection mechanism. Further research is necessary to uncover the reasons why these inconsistent patterns are observed. However, it should be clear that any interpretation of these data in terms of a competitive or noncompetitive selection mechanism is premature." (p. 7) (see also Jescheniak, Schriefers, & Lemhöfer, 2012b).

In sum, at this point, it is unclear whether determiner selection is competitive, and if so at which level: word form or lemma. However, given our suggestion of competitive noun lemma selection, competition between determiners at the lemma level (at least) would seem a logical extension.

Challenges and future directions

It is obvious from our discussions above that there are many aspects of the representation and processing of lexical syntax that remain uncertain. Here we briefly recap the more thorny of the issues we have raised and touch on a few others, in the hope that it may inspire further research that can test and develop the model we have presented here.

The nature of determiner selection

We noted above the extensive debate regarding whether competition exists at all in spoken word production. We further noted that we favoured an account that included competition, at least between lemmas. As there is no principled reason to have competition for noun lemmas and not for determiner lemmas, it is logical for determiners also to compete at the lemma level. However, this then brings us to the observation that production of plural noun phrases with nouns that take determiners that are equivalent across singular and plural shows a different pattern (a relative benefit) compared to noun phrases with nouns where the determiners differ across singular and plural. This seems to imply either that determiner selection is not competitive or that determiners that share a form also share a lemma. However, much of this evidence comes from the picture-word interference task which arguably has rather different constraints to spontaneous language production. Even when the task is noun phrase production using pictures, the effects found are sensitive to task constraints (e.g. proportion of plural trials).

Consequently, we feel that it is premature to draw a conclusion in this domain and await with interest the results of further experimental investigation.

'*Default*' *activation of the plural affix*

Nonwords can be produced in the plural with the use of the plural affix. Consequently, we suggested that when the conceptual equivalent of plural, MULTIPLE, was activated, the plural suffix (-s in English) received weak

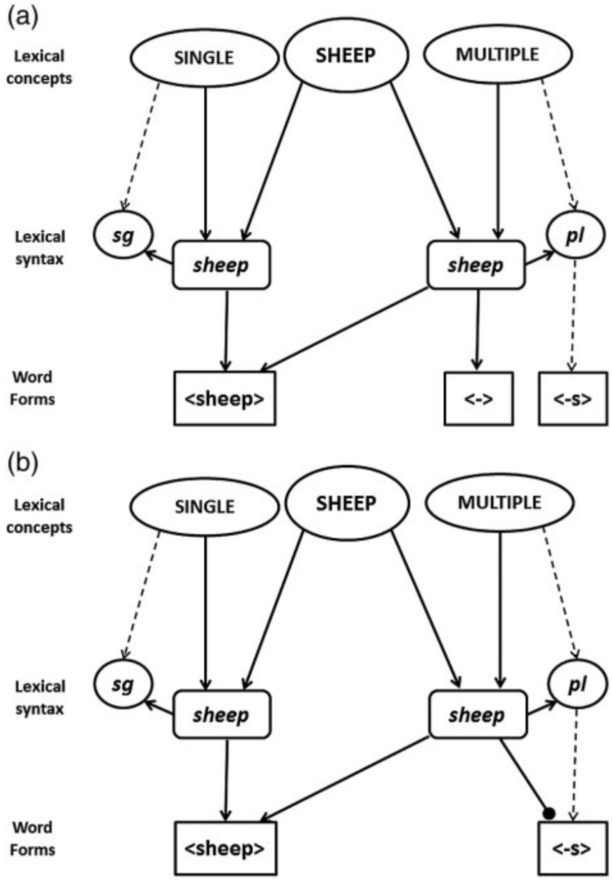

Figure 11. (a) Avoidance of overregularisation errors in zero plurals using a null affix. (b) Avoidance of overregularisation errors in zero plurals using inhibition.

activation via the plural lexical-syntactic diacritic. We further suggested that this could be the source of regularisation (e.g., *mouses*), and overregularisation errors (e.g., *mices*). However, if this weak activation is sufficient to allow affixation of nonwords, why does it not result in these errors routinely on irregular words (including zero plurals, mass nouns)? One, perhaps rather unsatisfactory, response could be that this activation is only sufficient in the absence of any other lexical activation. However, clearly the precise mechanism by which this could be implemented would need to be further specified. Another possibility is that overregularisations may be avoided through the use of internal monitoring (Levelt et al., 1999): Speakers may simply detect forms like "*sheeps*" or "*mouses*" by internal monitoring and repair. Two other alternatives are illustrated in Figure 11a and 11b which use the example of the zero plural *sheep* from Figure 6 (earlier). Figure 11a includes a null affix (see above for discussion of experimental evidence for and against null affixes). The representation of irregular or zero plurals would be such that the lemma would have connections to the null affix, rather than the -s affix for regular plurals. Hence, when the lemma of one of these plurals is activated, this null affix would be more highly activated than the -s affix and the overregularisation problem is overcome.

Figure 11b shows an alternative possibility, where the lemma of any word which does not require the plural affix will inhibit the affix – once again overcoming the over-generalisation problem.

Either of these two accounts seems plausible extensions to the theory, once again, however, future research will need to provide experimental support.

Complex inflectional systems

As we alluded to above, English is a poor choice for investigating lexical syntactic representation because of its relatively impoverished range of lexical syntax. The same is true with respect to inflectional morphology, particularly within the noun phrase. While we have explicitly avoided focus on the word form (morphological) level in this paper, it is nevertheless worth considering whether our account could deal with those languages where there is far richer inflectional morphology with number morphology also being influenced by other lexical syntactic factors, including case and gender (e.g. Russian – which also has an influence of animacy on the inflectional system). The most straightforward account is that, as in English, each noun lemma has links to both the stem and the appropriate plural suffix. However, in languages where case also influences suffixation, more than one suffix is activated by a particular (singular or plural) noun lemma. Hence, for example, in Russian, 'lake' has the stem *ozer*. In the singular, this is inflected with –o in the nominative and accusative cases (*ozero*), -a in the genitive case (*ozera)*, -u in the dative (*ozeru*), -om in the instrumental case (*ozerom*) and –e in the prepositional case (*ozere*). Hence, we would propose that the noun lemma for 'lake' has links to a word form of the stem <ozer> and suffixes <-o>, <-a>, <-u>, <-om> and <-e>. Similarly, in the plural, the same cases are affixed with –a (nominative, accusative), -am (dative), -ami (instrumental), -ax (prepositional) and no suffix (genitive). Hence, the plural lemma for 'lake' activates these corresponding suffixes (most probably including a null suffix). In order for the correct affix to be produced, we suggest that the lexical syntactic diacritic for case would directly activate those suffixes which correspond to that case. Consequently, the suffix with the greatest activation will be that which is activated both by the noun lemma and by the case. Further experimentation and computational modelling would be beneficial to test the adequacy of this account of suffixation.

Interactions between phonology and morphology

In many languages, including English, the suffix used varies according to the phonology of the target. For example, after a voiceless consonant in English, the suffix is /s/ (cats, cliffs), a voiced consonant /z/ (beds, sums) and /ɪz/ after fricatives and affricates (buses, hedges). As we have focused on lexical syntax, rather than morphology, we have not entered into the debate whether each of these represents a separate suffix, or whether there is a single 'abstract' suffix which is then modified according to phonological rules. Psycholinguistic accounts (and particularly computationally explicit accounts) of how such phonological rules might be applied are required to be able to develop and test hypotheses to discriminate between these two possibilities.

Connected speech

Another way in which the theory we have sketched needs further consideration is in the constraints which connected speech would put on processing. For example, to what extent do upcoming or previous words influence the activation of current words? It is now well established that upcoming words are active from word exchanges in speech error data (e.g., "wife for his job"; Fromkin, 1973). In addition, it is also clear that the conceptual number of previous words can influence upcoming words in the sentence: so-called agreement attraction (e.g. *the key to the cabinets were missing; e.g. Bock 2001; Bock & Middleton, 2011; Eberhard et al., 2005). Once again, further specification may allow predictions to be made and tested regarding patterns of behaviour that are more or less likely given the architecture and processing assumptions proposed here.

Acquisition and learning

The theory presented here, in common with the majority of theories in the psycholinguistic field, is proposed as a theory of the adult word production system. It does not speak to how the representations are acquired. While it is clearly in children that the issue of acquisition is most prominent, adults too acquire new nouns which must be integrated into the language system. Thus, *any* theory should ideally have a learning component. For example, when reading Harry Potter for the first time, or experiencing via the film or audio book, one might acquire "muggles" and "horcrux". How does the language system integrate these into the lexicon? Our theory does not come close to addressing this, but there are some pointers. For example, if a singular noun has been acquired (e.g. horcrux), then it can be inflected using the 'default' affixation procedure we discussed for non-words above. If the plural form of a noun is the first to be experienced (e.g. muggles), context will make it clear that it refers to multiple entities; thus, the meaning of the noun and the concept MULTIPLE will converge on a new lemma (MUGGLES). This new lemma might initially map onto a single (undecomposed) word form (<muggles>). This seems particularly likely for children at the early developmental stage before plural affixation has become productive. Presumably, in the adult, there is a learning mechanism which enables the representation as stem and suffix (perhaps in addition to full form). Mechanisms are also required to allow changes of weights over time to implement, for example, frequency effects (such as we propose for plural dominance).

It is clear that the next stage in the evolution of theory building is integrating learning mechanisms. It will be a vital test of our theories whether they are plausible both as learning theories and processing theories.

Conclusion

In order to provide a comprehensive theory of the representation of grammatical number in the mental lexicon, there are many factors that have to be considered. Primary amongst these are factors influencing agreement and particularly agreement where conceptual number and grammatical number diverge, as in the case of *pluralia tantum* (e.g. *scissors*) and mass nouns (e.g. *water*). We have presented arguments supporting the idea that conceptual number can influence grammatical number within the noun phrase.

We have made our ideas explicit through presenting a series of sketches of the architecture we favour. We have made it clear that, particularly with regard to processing assumptions, many different implementations may be compatible with the spirit of this model. While this is not a complete theory, we hope that, nevertheless, it provides a strong basis for future experimental and computational investigations.

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Notes

1. In the Hebrew stimuli, the plural was formed by adding a suffix to the singular form, like English plural formation.
2. Note: Biedermann et al. (2013) question the need for independent representations for singular and plural of plural dominant nouns at concept and lemma levels. While this may appear inconsistent with the model proposed here, in fact the critical point is that here, we argue for identical forms of representation for singular and plural dominant nouns at the concept and lemma levels. This is consistent with Biedermann et al. who argue *against* different representations at the concept and lemma levels for plural dominant and singular dominant stimuli.
3. There will, however, need to be a mechanism that ensures the correct use of quantifiers such as *a pair of, two pairs of*, etc.

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