Why No Mere Mortal Has Ever Flown Out to Center Field But People Often Say They Do[1]

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Abstract

The past tense has been the source of considerable debate concerning the role of connectionist models in explaining linguistic phenomena. In response to Pinker and Prince (1988), several connectionist models have been developed that compute a mapping between the present tense phonological form of a verb to a past tense phonological form. Most of these models cannot distinguish between homophones such as FLY-FLEW and FLY-FLIED (as in "flied out"). Kim, Pinker, Prince, & Prasada (1991) have suggested that the addition of semantic information to such nets will not provide an adequate solution to this homophony problem. They showed that English speakers use derivational status, rather than semantic information in generating past tenses. We provide evidence contradicting this account. Subjects' rated preferences for past tense forms are predicted by semantic measures; moreover, a simulation model shows that semantic distance provides a basis for learning the alternative past tenses for words such as FLY. We suggest a reconciliation of the two theories in which knowledge of "derivational status" arises out of semantic facts in the course of learning.

Introduction

The past tense of English verbs has provided a domain in which to explore the role of connectionist models in explaining linguistic phenomena. Traditional linguistic theory holds that the regular past tense (e.g. WALK-WALKED) is formed by rule, whereas irregular past tenses such as SEE-SAW are learned by rote. In a series of papers, Pinker and his colleagues have developed variants of this view (Pinker & Prince, 1988; Kim et al., 1991; Prince, 1991; Marcus, Pinker, Ullman, Hollander, Rosen, & Xu, 1992). Taken with the shortcomings of Rumelhart and McClelland's (1986) model of the past tense, their observations suggested that connectionism had little to add to the traditional linguistic account. Subsequent work has indicated that various aspects of past tense formation can be simulated by connectionist nets, however (e.g., Plunkett & Marchman, 1991; Cottrell & Plunkett, 1991; MacWhinney & Leinbach, 1991; Hoefner, 1992; Daugherty & Seidenberg, 1992, in press; Seidenberg, 1992). These models suggest that Pinker et al.'s views concerning the role of connectionist models in explaining linguistic phenomena may have been overly pessimistic.

Pinker (1991) and Kim et al. (1991) describe some past tense phenomena that remain problematical for connectionist models. These concern homophonous verbs with different past tense forms. For example, the past tense of the verb FLY (meaning "airborne movement") is FLEW. There is an alternative, baseball-related sense of FLY, the past tense of which is FLIED ("the batter flied out to center"). Connectionist models that map from the phonological form of the present tense to the phonological form of the past tense (such as Rumelhart & McClelland's) cannot learn such alternative forms (see, however, MacWhinney & Leinbach, 1991; Hoeffner, 1992). This limitation has been repeatedly mentioned as a failing of connectionist models of the past tense (see Pinker & Prince, 1988; Marcus et al., 1992; Pinker, 1991).

One obvious suggestion is to solve the homophony problem by introducing semantic information. For example, the conjunction of the phonological form FLY and the meaning "airborne movement" would indicate that the past tense is FLEW, whereas the conjunction of FLY and the meaning "creating a fly ball" would indicate FLIED. Generation of the past tense would be treated as a constraint satisfaction problem in which there are partial cues from phonology, meaning, and possibly other sources. Pinker (1991) and Kim et al. (1991) suggest that this solution will not work, however. They observe that the semantics of verbs are not very good predictors of past tense morphology. Thus, STRIKE, HIT, and SLAP are semantically similar but their past tenses are formed in three ways: vowel change (STRUCK), no change (HIT), and rule (SLAPPED). Pinker (1991) believes that a network encoding relationships between meaning and phonology

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will necessarily tend to form the same type of past tense for semantically-related verbs. It is well known, however, that nets with attractors (e.g., Hinton & Shallice, 1991; Hoeffner, 1992) can learn to map similar inputs onto dissimilar outputs without massive interference or overgeneralization.

A more serious problem is that Kim et al. provide evidence that the derivational status of a verb—whether it is derived from an existing noun or verb—determines past tense morphology, not semantics. Subjects were asked to rate their preferences for regular vs. irregular forms of verbs that were derived from either nouns (denominals) or verbs (deverbals). Consider FLY again. According to Kim et al., the sense of FLY in (1a) is derived from the noun FLY [fly ball]. The sense of FLY in (2b) is said to derive from the verb FLY [airborne movement]. In general, subjects preferred the regular past tense for denominals and the irregular past tense for deverbals. Thus, derivational status apparently determined the formation of the past tense.

Denomial:

1. Wade Boggs has a bad habit of hitting fly balls into center field.

a. Yesterday, he got one hit, and then flied out twice.

b. Yesterday, he got one hit, and then *flew out twice.

Deverbal:

2. The math professor flies off the handle at the slightest things.

a. Last week, he *flied off the handle when one student talked during class.

b. Last week, he flew off the handle when one student talked during class.

An alternative hypothesis (Lakoff, 1987) is that past tense preferences are determined by the distance between the meaning of the derived verb and the central meaning of the existing irregular verb (see Fig. 1). The past tenses of FLY [out to center] and FLY [off the handle] are determined by their distances from the central meaning of FLY [airborne movement]. Subjects preferred FLEW [off the handle] because it is closer to the central meaning of FLY, and FLIED [out to center] because it is more remote. However, Kim et al.'s data only partially supported this account. Rated distance from the central meaning was correlated with past tense preferences; however, there were residual effects attributable to derivational status. Thus, the authors concluded that the facts cannot be explained entirely in terms of semantic distance.

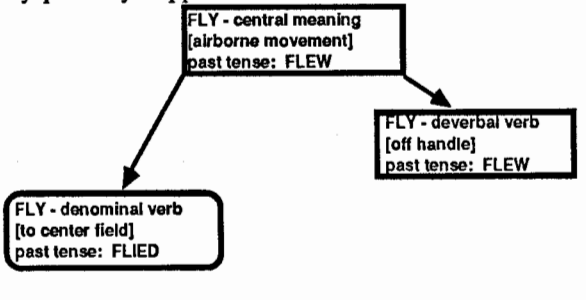

Figure 1: Hypothesis that past tense of derived form should depend on distance from central meaning.

Of course, there is nothing about connectionist models that precludes encoding derivational status as a constraint on past tense formation. Nonetheless, we thought it might be premature to abandon the semantic distance hypothesis. There are two principal issues. The first is that there is some question about the relevant measure of semantic distance. Kim et al., following Lakoff's informal suggestion, assessed distance from the central meaning. However, FLY has several secondary meanings: "to rush; to run;" "to flee; to try to escape;" "to react explosively; to burst." We will collectively refer to these as the "aggressive motion" sense of FLY, all of which take the irregular past tense. The fact that the past tense of FLY [off the handle] is FLEW would be explained by its relative proximity to FLY [aggressive motion]. The fact that the past tense of FLY [out to center] is FLIED follows from the fact that it is more distantly related to either primary sense of the verb FLY (Fig. 2). Harris (1992) obtained a measure of the distance of a derived meaning from the closest existing verb meaning, rather than the "central" meaning. This semantic distance measure was again correlated with past tense preferences. However, derivational status still accounted for a significant portion of the variance in her data. Hence, Harris suggested that both semantic distance from existing meanings and derivational status are relevant.

A second problem concerns the derivational status factor itself. Pinker (1991) and Kim et al. (1991) assume that grammatical category — whether a word is a noun or verb — determines the derivation of the past tense. Derivational status is quite confounded with semantic distance from existing verb meanings, however. In general, deverbals are closer in meaning to existing meanings than are denominals. Deverbals such as "break in a new employee" or "fly off the handle" typically overlap with or metaphorically extend an existing meaning. Denominals, however, are derived from a noun that happens to sound like an existing verb but can be completely unrelated in meaning to it. For

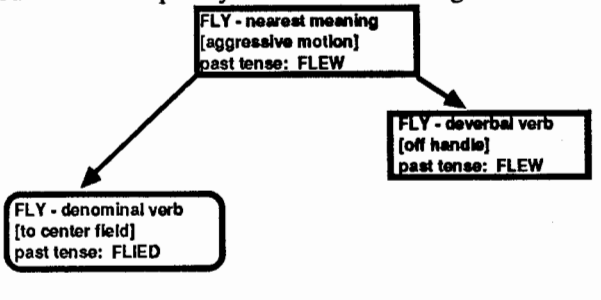

Figure 2: FLY [off handle] is related to FLY [aggressive motion], not FLY [airborne movement]

example, Kim et al. compared preferences for the deverbal BREAK (he breaks/broke in the new employees) and the denominal BRAKE (he brakes/braked for animals; see Fig. 3). Although BREAK and BRAKE are homophonous, the regular past is preferred for the denominal and the irregular past for the deverbal. BRAKED, however, is derived from the noun BRAKE, which is wholly unrelated to any meaning of BREAK. In contrast, deverbal BREAK is semantically related to an existing sense of BREAK. Harris' (1992) data indicate this clearly. She obtained ratings of the distance of Kim et al.'s verbs from their nearest homophonous irregular past tense. Denominals were rated as being further from an existing meaning (mean = 4.75 on 6-point scale) than deverbals (mean = 2.35). This difference is highly reliable, $t(1,36) = 10.4$, $p < .001$.

In sum, there is a confound between derivational status and distance from an existing irregular verb in the Kim et al. materials. One way to avoid this would be to include an equal number of deverbals derived from wholly unrelated verb homophones. For example, WRITE-RIGHT (as in "righted the boat") would be analogous to BREAK-BRAKE. Kim et al. instead dealt with the confound statistically, performing regression analyses indicating that derivational status accounted for unique amounts of variance after semantic distance was partialled out. This analysis cannot be taken as definitive, however. The factor labelled "derivational status" could simply have been coding other aspects of semantic distance not captured by their other measure.

We explored these issues further in the research described below. We first obtained a second measure of semantic distance, providing further evidence concerning the relevance of this factor. We also conducted simulations which addressed whether a connectionist model could learn the past tenses of homophonous verbs using semantic distance as a cue.

Behavioral Data

Pinker and colleagues' theory elegantly suggests that a single factor, derivational status, should predict past tense preferences: Irregular forms will be used for deverbals and regular forms for denominals. Our view is that verb preferences are based on the distance between the meaning of a verb and the meaning of a homophonous irregular verb. BROKE, for example, cannot be the past tense of BRAKE because it is dissimilar in meaning to BREAK.

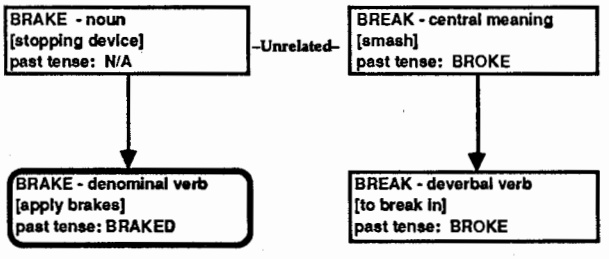

Figure 3: BRAKE(v) is related to BRAKE (n) which is unrelated to BREAK

Subjects' ratings in the Kim et al. study departed from what the simple theory predicts. Verbs varied greatly in the degree to which the regular past tense was preferred over the irregular past. For example, whereas subjects greatly preferred BRAKED (not BROKE) as the past tense of BRAKE, there was only a small advantaged for FLIED (over FLEW) as the past tense of "fly out." Moreover, for several denominals, the irregular pasts were actually preferred overall. These deviations from the predicted patterns were attributed to subjects' "uncertainty" about the derivational status of individual items. This uncertainty was not independently assessed, however. Our view is that subjects' preferences are based on the distance from existing irregular verb meanings. Kim et al. partitioned this distance into two components: "derivational status" (denominals are more distant than deverbals) and "uncertainty" (which reflects the relative distance from existing meanings).

We examined these issues by obtaining a second measure of semantic distance. For all denominal verbs used by Kim et al. we had subjects rate their distance from the source noun. The hypothesis was that this distance would account for variability in subjects' responses that Kim et al. attributed to "uncertainty" over derivational status.

Fifteen native English-speaking USC undergraduates volunteered to participate in the experiment. The 37 present tense denominal passages from Kim et al. were presented as in the example below:

The general is going to order his artillery to form a ***ring*** *around the city. But if he* ***rings*** *the city with artillery, then a battle is certain.*

Subjects were told to rate the similarity of the meaning of the verb in bold to the meaning of the noun homophone on a 6 point scale (1 = very similar; 6 = very dissimilar).

Multiple regression analyses were performed on Kim et al.'s preference ratings (preference for regular over irregular past tense) for the 37 denominals in their experiment. The mean semantic distance to the nearest homophonous verb (from Harris, 1992) and the mean semantic distance to the homophonous noun (from this experiment) were the predictor variables. Distance to verb uniquely accounted for 20.5% of the variance in preference ratings, $F(1,34) = 9.002, p < .01$. Distance to noun accounted for an additional 20% unique variance, $F(1,34) = 8.599, p < .01$.

These results strongly indicate that subjects' past tense preferences depend on semantic factors. The regular past is preferred when the intended meaning

(e.g., past tense of BRAKE) is far from an existing irregular verb and close to the source noun. The irregular past is preferred when the distances are in the opposite directions. These data indicate that variability that Kim et al. attributed to "uncertainty" over derivational status is instead due to semantic distance.

For the deverbals, the semantic distance measure also correlated with subjects preference ratings r = .26. Because deverbals are derived from verbs, not nouns, there were no data concerning their distance from a "source noun." In keeping with the hypothesis that derivational status merely indicates semantic distance, we conducted an omnibus analysis of both types of verbs in which deverbals were assigned the maximally unrelated score on the "distance from noun" measure (thus, for example, BREAK was rated as unrelated to BRAKE). Derivational status and distance to the noun were correlated -.84, because denominals (coded 1) were closer to the noun and deverbals (coded 0) were farther. Derivational status and distance to the verb were correlated .75, because denominals were further from the verb and deverbals closer. These data are consistent with the hypothesis that derivational status merely encodes semantic distance.

In the multiple regression, the relationships between the predictor variables and the past tense preference ratings were as follows. All three measures were highly intercorrelated: noun distance and derivational status = -.84; noun distance and verb distance = -.61; verb distance and derivational status = .75. None of the predictor variables by itself significantly accounted for unique variance in the past tense preference ratings. The confounded effect of the three predictors, however, is highly significant, $F(1,72) = 74.774$, $p < .001$). These results indicate that the predictor variables are capturing the same information, which can be termed distance between the verb's meaning and the meanings of homophonous words. These results differ from Kim et al.'s, which showed that derivational status accounted for unique variance in the ratings. Once the second measure of semantic distance was included, however, the unique effects of derivational status were removed.

In summary, these data suggest that preferences concerning the past tense can be explained in terms of semantic distance, provided that it is measured appropriately, obviating the role of derivational status.

Connectionist Model of the Past Tense

We then explored how connectionist models might deal with these phenomena. This work builds on research described in Daugherty and Seidenberg (1992). The architecture of the basic model is a simple feed-forward network with input, hidden, and output layers. The input layer represents the phonological form of a monosyllabic verb in English, conforming to a CCCVVCCC template. Each segment is represented by 8 articulatory features and a sonority hierarchy. The features are back, tense, labial, coronal, velar, nasal, sibilant, and voiced, which are represented by two units each corresponding to the presence or absence of the feature. The sonority hierarchy ranges from 1 to 7 and is represented by 7 units. This results in 23 units being dedicated to each segment in the template, or 184 total phonological units. If a feature is active for a segment, its value is set to 1.0; if not, its value is 0.0. Unused segments have all units set to 0.0. The output layer represents the phonological form of either a monosyllabic or bisyllabic verb and is made up of 368 units. We chose to allow bisyllabic outputs so that present/past tense pairs such as PUNT-PUNTED could be represented (we use orthography here to represent the phonological code for typographical convenience). As in our previous model, the phonological representations are centered on the nucleus of the syllables, as shown in Figure 4. There are 150 hidden units in the model. During training, the phonological form of a regular, exception, deverbal, or denominal verb is activated on the input units along with an encoding of its semantic distances to the closest verb and noun definitions. The task of the model is to generate the phonological form of the past tense on the output units.

The model encodes the two measurements of semantic distance by augmenting the input layer with two separate vectors. One vector represents the distance of a present/past tense pair to the closest verb definition and the other represents the distance to the closest noun definition. Each vector ranges in value from 1 (closely related) to 6 (not related) and is represented by 15 units. The theory here is that people are able to judge semantic distances and that this information enters into the computation of the past tense. We have not attempted to simulate the similarity-judgment process, however. As in the other version of the model, deverbals were trained to produce the exception past tense form and denominals were trained to produce the regular past tense form. A few examples are shown in Table 1.

As seen in the table, regular verbs like BAKE-BAKED and irregular verbs like BREAK-BROKE are presented with a semantic distance of 0.0 to their closest verb definition and a semantic distance of 6.0 to their closest noun definition, indicating that BAKE and BREAK correspond to central and not extended verb meanings. Deverbals and denominals are presented with their closest semantic distance to a homophonous exception verb, as reported in Harris (1992). An encoding of their closest semantic distance to a homophonous noun, as reported in this paper, is also included. In the examples above, the distance of the deverbal FLY-FLEW to the exception verb FLY-FLEW was rated by subjects to be 2.0 and its distance to the closest noun homophone was set to be 6.0, since deverbals are not derived from nouns. The distance of the denominal FLY-FLIED to the exception verb FLY

Table 1: Semantic distance measurements

Present Tense	Sem. Dist. to Verb	Sem. Dist. to Noun	Past Tense	Used in Context
BAKE	0.0	6.0	BAKED	John BAKED a pie. (regular)
BREAK	0.0	6.0	BROKE	Sally BROKE the vase. (exception)
FLY	2.0	6.0	FLEW	He FLEW off the handle. (deverbal)
FLY	2.5	1.7	FLIED	He FLIED out to center field. (denominal)

FLEW was rated by subjects to be 2.5 and its distance to the noun FLY (ball) was rated to be 1.7.

During training, all regular and exception verbs were probablistically presented to the model according to their Francis & Kucera (1982) frequencies. Denominals and deverbals were probablistically presented during 10% of the epochs. Weight correction was by standard back-propagation (Rumelhart, Hinton, & Williams, 1986). In scoring the performance of the model, we compared the generated output for each segment to an inventory of known segment representations. The output of the model was considered correct only if the target output segments provided the best fit for all generated segments. We also calculated the total sum of squared error for all output units as a measure of goodness of fit.

For the training set, all 367 regular monosyllabic verbs with a Francis & Kucera frequency greater than 1 were chosen. An analysis of the Francis & Kucera corpus revealed that exception verbs comprise 5% of all listed verb types and 22% of the verb tokens. Thus, we selected 20 exception verbs from the Kim, et al. data to maintain the correct relative verb type proportion. Exception verb classes and subclasses, as identified by Pinker & Prince (1988), were represented within the training set by selecting verbs with the appropriate token frequencies from these classes. Each exception verb was also represented both as a deverbal and as a denominal in the training set by encoding semantic distances.

Training progressed for 700 epochs, at which point performance approached asymptote. The following results reflect averages of three training sessions with random initial weights. All 367 of the regular verbs were learned (100%). 18 of the 20 exception verbs were learned (90%). The errors were LIGHT-LET, a vowel feature error, and RING-RANGED, an over-regularization error. 18 of 20 deverbals were learned (90%) and 20 of 20 denominals (100%).

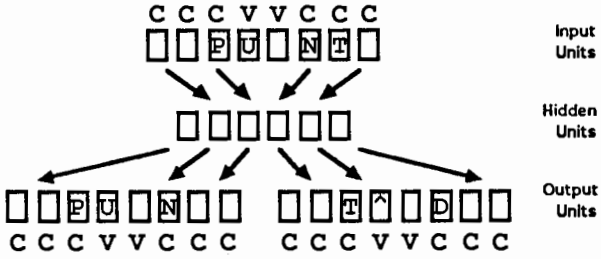

Figure 4: Architecture of the model

We performed a simple regression using the error score for generated deverbals and denominals in the model as the predictor variable and past tense preference ratings as the predicted variable. We found that by training a model on only the phonological form of verbs and an encoding of their semantic distances to the closest noun and verb definitions, the model's performance accounts for a significant amount (21.8%) of the variance in people's preference ratings, $F(1,16) = 9.462$, $p < .01$.

Discussion

Pinker (1991) and Kim et al. (1991) theorize that derivational status determines the past tense of verbs that sound like existing irregular verbs. This places the explanation for the FLY/FLEW/FLIED facts at a morphological level of representation that governs the organization of the mental lexicon. In generating past tenses for homophones, people are thought to follow a simple rule: if the verb is derived from a noun, use the regular past; if derived from an existing irregular verb, use its irregular past tense. Deviations from the predictions of this rule are explained in terms of uncertainty about derivational status.

We have explored an alternative hypothesis, which holds that past tense preferences are subject to semantic constraints. The way in which the past tense of a novel verb is realized depends on the relationship between the meaning of the new verb and the meanings of the noun or verb from which it is derived. If the novel verb is similar in meaning to an existing irregular verb, the latter's past tense form can be used. If the novel verb is dissimilar in meaning to an existing irregular verb (because, for example, it is derived from a semantically-unrelated noun, as in BREAK-BRAKE), this contraindicates using the existing verbs's past tense. Thus, BROKE cannot be recruited for the past tense of BRAKE because it already has the meaning "past tense of BREAK". Preferences then depend on the degree of semantic distance, rather than the deverbal-denominal dichotomy. FLY is especially complex because, as the ratings indicate, the baseball sense of flying out is semantically related to both the source noun (fly ball) and an existing irregular verb (fly-airborne motion). That is why subjects sometimes say "flew out to center

field" even though the derivational theory predicts that it should always be "flied".

This account explains the phenomena in terms of the communicative consequences of using an existing irregular form as the past tense of a novel verb. A marked form can only be used if its meaning is intended. If its meaning is not intended—as in the case of a semantically unrelated homophone— a different form must be used instead. The regular form is used to distinguish the meaning of the novel form from that of the homophonous irregular verb. Performance then depends on the degree to which a novel verb sense is judged to be related to existing noun and verb senses.. Similarity to existing forms act as soft constraints pulling subjects' preferences either toward or away from a given past tense form.

Our behavioral data and simulations are consistent with this semantically-based account. The data indicate that derivational status is confounded with semantic distance. Both distance from existing irregular verb and distance from source noun affect subjects' preferences concerning the past tenses of denominals. The same factors also apply to deverbals. A model that encodes these measures of semantic distance is able to perform at a high level and comparably to people in generating the past tense.

We suggest that the two theories of the past tense can be reconciled by considering how people acquire knowledge of a word's "derivational status." This information derives from facts about how words are used and what they mean. Pinker (1984), among others, has suggested that knowledge of a word's syntactic category arises out of facts about lexical semantics (the so-called "semantic bootstrapping hypothesis" of syntactic category learning). Our models can be taken as showing how such categories arise. They arise, for example, out of observations of semantic similarity and dissimilarity — the "distances" measured by our ratings. Looking down at the model and attempting to formulate a high-level description of what it had learned, one could say that it had captured the distinction between denominal and deverbal verbs. Importantly, it did so on the basis of semantic information, rather than a morphological representation. Thus, where Pinker's treatment of the past tense takes notions such as "derivational status" as primitive, we consider it to be secondary to facts about semantic space. The morphological theory therefore provides an approximate, folk-psychological description of what our nets achieve.

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