A connectionist model of the retreat from verb argument structure overgeneralization.

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A central question in language acquisition is how children build linguistic representations that allow them to generalize verbs from one construction to another (e.g., *The boy gave a present to the girl* → *The boy gave the girl a present*), whilst appropriately constraining those generalizations to avoid non-adultlike errors (e.g. *I said no to her* → **I said her no*). Although a consensus is emerging that learners solve this problem using both statistical and semantics-based learning procedures (e.g., entrenchment, pre-emption and semantic verb class formation), there currently exist few – if any - proposals for a learning model that combines these mechanisms. The present study used a connectionist model to test an account that argues for competition between constructions based on (a) verb-in construction frequency, (b) relevance of constructions for the speaker's intended message and (c) fit between the fine-grained semantic properties of individual verbs and individual constructions. The model was able not only (a) to simulate the overall pattern of overgeneralization-then-retreat, but also (b) to use the semantics of novel verbs to predict their argument structure privileges (just as real learners do) and (c) to predict the pattern of by-verb grammaticality judgments observed in adult studies.

Keywords: Connectionist model, retreat from overgeneralization, no-negative-evidence problem, DO-dative, PO-dative.

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overgeneralization.

The centerpiece of Chomsky's (1957) landmark *Syntactic Structures* was the observation that speakers' knowledge of their native language does not consist solely of an inventory of rote-learned sentences; rather speakers acquire abstract generalizations which allow them to comprehend and produce utterances that they have never heard before. The question of how children acquire this quintessentially human ability occupies a core place in language acquisition research.

Braine (1971) pointed out a paradox that lies at the heart of this ability. On the one hand, even 2-3 year old children are adept at producing and understanding sentences in which a verb is used in a sentence-level *verb-argument structure construction* in which it has never appeared in the input. For example, when taught a novel verb in an *intransitive inchoative* construction (e.g., *The sock is weefing*), children are able to produce a *transitive causative* sentence with this verb (e.g., *The mouse is weefing the sock*; e.g., Akhtar & Tomasello, 1997; see Tomasello, 2003; Ambridge & Lieven, 2011, for reviews, and Gertner, Fisher & Eisengart, 2006; Noble, Rowland & Pine, 2011, for similar findings in comprehension).

On the other hand, children must somehow restrict this productivity to avoid producing ungrammatical utterances. While many verbs can appear in both the intransitive inchoative and transitive causative constructions (e.g., *The ball rolled / The clown rolled the ball*), and children must be able to generalize from one to another, they must also learn that certain verbs are restricted to the former (e.g., *The man laughed / *The clown laughed the man* [where * indicates an ungrammatical utterance]). Indeed, evidence from both diary and elicited production studies

demonstrates that many children pass through a stage in which they produce these

types of overgeneralizations, before "retreating" from error (e.g., Bowerman, 1988;

Pinker, 1989; Brooks, Tomasello, Dodson & Lewis, 1999; Brooks & Tomasello, 1999;

Brooks & Zizak, 2002). Analogous errors for the observed for the dative and locative

alternations are summarized in Table 1.

Table 1. Possible and attested verb argument structure overgeneralization errors.
Attested errors (all from Bowerman, 1988) are shown in **bold**, with the age of the child
(years;months) and a possible grammatical formulation using the alternate
construction. Reproduced by permission of Wiley from Ambridge, B., Pine, J.M.,
Rowland, C.F., Chang, F. & Bidgood, A. (2013). The retreat from overgeneralization
in child language acquisition: Word learning, morphology and verb argument
structure. *Wiley Interdisciplinary Reviews: Cognitive Science, 4*: 47–62.

	Transitive causative alternation	
	(a) (Inchoative) Intransitive	**(b) Transitive (causative)**
Alternating	The ball rolled	The man rolled the ball
(a) only	The man laughed Do you want to see our heads disappear? I don't want any more grapes; I'll cough I (didn't) giggle(d) Will I climb up there? Did it bleed? I always sweat [when I wear it] [They're nice enough that] I wish I had one	*The clown laughed the man ***Do you want to see us disappear our heads? (6;0)** ***I don't want any more grapes; they just cough me (2;8)** ***Don't giggle me (3;0)** ***Will you climb me up there (3;2)** ***Did she bleed it? (3;6)** ***It always sweats me** ***[They're nice] enough to wish me that I had one (5;8).**

	Dative alternation	
	(a) Prepositional-object (PO) dative	**(b) Double-object (DO dative)**
Alternating	The boy gave a present to the girl	The boy gave the girl a present
(a) only	The boy dragged the box to the girl The boy suggested the trip to the girl I said no to her Shall I whisper something to you?	*The boy dragged the girl the box *The boy suggested the girl the trip ***I said her no (3;1)** ***Shall I whisper you something? (7;8)**

	Locative alternation	
	(a) Contents (figure) locative	**(b) Container (ground) locative**
Alternating	The boy sprayed paint onto the statue	The boy sprayed the statue with paint
(a) only	The boy poured water into the cup Mommy, I poured water onto you I don't want it because I spilled orange juice onto it	*The boy poured the cup with water ***Mommy, I poured you [M: You poured me?] Yeah, with water (2;11)** ***I don't want it because I spilled it of orange juice (4;11)**
(b) only	*The boy filled water into the cup ***I'm gonna cover a screen over me (4;5)** ***Can I fill some salt into the bear [-shaped salt**	The boy filled the cup with water I'm going to cover myself with a screen Can I fill the bear with salt?

shaker]? (5;0)	

The problem of the retreat from overgeneralization has attracted a considerable amount of attention in the literature. Recent studies of all three types of overgeneralization error listed in Table 1 have provided support for three proposals.

Under the *entrenchment hypothesis* (e.g., Braine & Brooks, 1995), repeated presentation of a verb (regardless of sentence type) contributes to an ever-strengthening probabilistic inference that its use in non-attested constructions is not permitted. In support of this hypothesis, many studies have demonstrated a negative correlation between overall verb frequency (regardless of sentence type) and the relative acceptability and production probability of errors with that verb, in judgment and production tasks respectively. (Brooks, Tomasello, Dodson & Lewis, 1999; Theakston, 2004; Wonnacott, Newport & Tanenhaus, 2008; Stefanowitsch, 2008; Ambridge, Pine, Rowland & Young, 2008; Ambridge, Pine, Rowland, Jones & Clark, 2009; Ambridge, Pine, Rowland & Chang, 2012; Ambridge, Pine & Rowland, 2012; Ambridge & Brandt, 2012; Ambridge, 2013; Ambridge, Pine, Rowland, Freudenthal & Chang, 2014; Bidgood, Ambridge, Pine & Rowland, 2014).

The *pre-emption hypothesis* (e.g., Goldberg, 1995) is similar, but with one important difference. Under entrenchment, a particular error (e.g., **Bart dragged Lisa the box*, where a PO-only verb is used in a DO-dative) is probabilistically blocked by any use of the relevant verb (e.g., *The man dragged the box; The boy dragged his feet; That movie really dragged on* etc.). Under pre-emption, errors of the form **Bart dragged Lisa the box* are probabilistically blocked only by uses that express the same intended message; i.e., PO-dative uses of that verb (e.g., *Marge dragged the package to Homer*). Thus this hypothesis predicts a negative correlation between the acceptability/production probability of a particular error (e.g., DO-dative uses of *drag*)

and the frequency of that verb in the single most nearly synonymous construction (e.g.,
PO-dative uses of *drag*). Although the two measures tend to be highly correlated,
recent studies suggest that – to the extent to which they can be differentiated
statistically – pre-emption plays a role above and beyond entrenchment (e.g., Brooks &
Tomasello, 1999; Brooks & Zizak, 2002; Goldberg, 2011; Boyd & Goldberg, 2011;
Ambridge, Pine & Rowland, 2012; Ambridge, 2013; Ambridge et al, 2014).

The *semantic verb class hypothesis* (Pinker, 1989) argues that learners form
classes of verbs that are restricted to particular constructions only. For example,
focusing on the dative alternation, verbs of accompanied motion and manner of
speaking may appear in the PO-dative (e.g., *Marge pulled the box to Homer; Homer
shouted the instructions to Lisa*), but are less than fully acceptable in the DO-dative
(e.g., **Marge pulled Homer the box; *Homer shouted Lisa the instructions*). On the
other hand, verbs of giving and illocutionary communication may appear in both
constructions (*Lisa gave the book to Bart, Lisa gave Bart the book; Lisa showed the
answer to Homer, Lisa showed Homer the answer*). Evidence for this hypothesis
comes from production and judgment studies showing that if children are taught novel
verbs, they use their notional semantic class membership to determine the
constructions in which they can and cannot appear (Gropen, Pinker, Hollander,
Goldberg & Wilson, 1989; Gropen, Pinker, Hollander & Goldberg, 1991a, 1991b;
Brooks & Tomasello, 1999; Ambridge et al, 2008, 2009; 2011; Ambridge, Pine,
Rowland & Chang, 2012; Bidgood et al, 2014).

Importantly, these semantic classes are not arbitrary. Rather, a particular class
of verbs can appear in a particular construction only if there is sufficient overlap
between the semantics of the verbs and the semantics of the construction. For example,
the DO-dative construction is associated with the meaning of "causing to have"

(Pinker, 1989). Thus the reason that verbs from the *give* and *show* classes may appear in this construction is that they are consistent with this meaning (in the latter case, the possession transfer is metaphorical; a transfer of information). On this account, the reason that verbs from the *pull* and *shout* classes may not appear in the DO-dative construction is that they are not sufficiently consistent with this "causing to have" meaning. Instead, they are restricted to the PO-dative construction, because they are compatible with the meaning of this construction ("causing to go"). Ambridge et al (2014) found that independent ratings of the extent to which particular verbs were consistent with "causing to have" versus "causing to go" significantly predicted the rated acceptability of that verb in the DO- versus PO-dative construction (see Ambridge, Pine & Rowland, 2012; Ambridge & Brandt, 2013, for an analogous finding for the locative alternation).

In summary, previous studies have found support for the entrenchment, pre-emption and semantic verb class hypotheses. This raises the question of whether it is possible to posit a single learning mechanism that yields all of these effects (indeed, it is debatable whether any of these proposal indeed constitute mechanistic accounts of the retreat from error *per se*). One proposal for such a learning mechanism is the *FIT*[i] account (Ambridge & Lieven, 2011; Ambridge, Pine & Rowland, 2012; Ambridge, Pine, Rowland & Chang, 2012; Ambridge, 2013; Ambridge et al, 2014).

The central assumption of the account is that speakers maintain an inventory of argument structure constructions - each acquired by abstracting across concrete tokens of those constructions in the input – which, in production, compete to express the speaker's desired message (e.g., MacWhinney, 2004). The activation level of each competitor is determined by three factors[ii], illustrated here for the example message "MARGE CAUSED HOMER TO HAVE THE BOX BY PULLING THE BOX

TO HOMER":

- ***Verb-in-construction frequency.*** The verb in the message (here *pull*) activates each construction in proportion to the frequency with which it has appeared in that construction in input sentences. This factor yields pre-emption effects because every input occurrence of *pull* in a PO-dative boosts the activation of this construction, at the expense of the DO-dative construction, in production. This factor yields entrenchment effects because every input occurrence of *pull* in *any* other construction (e.g., a simple transitive) boosts the activation of this construction at the expense of the DO-dative.

- ***Relevance***. A "relevant" construction is one that contains a slot for every item in the speaker's message. So, for the present example, both the PO-dative (yielding *Marge pulled the box to Homer*) and the DO-dative (**Marge pulled Homer the box*) are more relevant than, for example, the transitive (*Marge pulled the box*). The notion of relevance captures the intuition of the pre-emption hypothesis that the PO- and DO-dative are better competitors for one another than are other constructions such as the transitive.

- ***Fit***. The third factor is the compatibility (or *fit*) between the semantic properties of each item in the message (e.g., the verb) and the relevant slot in each candidate construction. The semantics of each slot are a frequency-weighted average of the semantics of each item which appeared in that position in the input utterances that gave rise to the construction. This factor is designed to capture the finding that ratings of the extent to which verbs exhibit semantic properties to do with "causing to have" and "causing to go" predict acceptability in the DO- and PO-dative respectively (Ambridge et al, 2014).

Of course, as a verbal model, the FIT account is little more than a redescription of the experimental findings. Thus the aim of the present study is to instantiate the account as a computational model in order to investigate the extent to which it can simulate (a) the overall pattern of generalization to novel verbs, overgeneralization errors and subsequent retreat shown by children and (b) the verb-by-verb pattern of adult acceptability ratings for overgeneralization errors in judgment studies. Before introducing the computational model itself, it is important to consider the respects in which it differs from previous models that also simulate aspects of the retreat from overgeneralization. Note that each of these models shares a degree of theoretical and implementation overlap with the present model, and thus should be considered complementary models, rather than radically different rivals.

Like the present model, the hierarchical Bayesian model of Perfors, Tenenbaum and Wonnacott (2010) learns item-based links between particular verbs and the PO- and DO-dative constructions. An important difference it that it generalizes to novel verbs by additionally forming *overhypotheses* regarding the tendency of (a) all verbs and (b) classes of distributionally similar verbs to occur in both constructions as opposed to only one, rather than on the basis of semantic similarity (the same is true for related models based on the notion of Minimum Description Length; e.g., Dowman, 2000, submitted; Onnis, Roberts & Chater, 2002; Hsu & Chater, 2010; Hsu, Chater & Vitányi, 2011, 2013). Although some versions of the Perfors et al (2010) model include verb-level semantic features, each feature has only three possible values - corresponding to PO-only, DO-only and alternating verbs – and so does not simulate fine-grained by-verb semantic effects observed for human participants (Ambridge et al, 2014).

The dual-path model of Chang (2002; see also Chang, Dell & Bock, 2006 is able to simulate a wide range of language acquisition phenomena, including generalization of novel verbs into unattested constructions and the retreat from overgeneralization (including for the dative alternation; see p.638-640). The model works by learning to sequentially predict the next word in a sentence (using a Simple Recurrent Network), given a message (e.g., AGENT=*Marge*, ACTION=*drag*, GOAL=*Homer*, PATIENT=*box*) and construction-level event semantics (e.g., CAUSE+MOTION+TRANSFER for the PO-/DO-dative). Due to its sequential nature, the dual-path model constitutes a lower-level and hence more realistic approximation of the task facing real language learners than any of the other models outlined here (including the new model outlined in the present article). An important difference from the present model is that the dual-path model does not represent verb-level semantics (only construction-level event-semantics). Also, its use of artificially-generated datasets means that the model does not make predictions regarding by-verb patterns of adult grammaticality judgments.

Perhaps the model closest to the present simulation is that of Alishahi and Stevenson (2008). This model receives input in the form of pairs of a scene and an utterance (e.g, DRAG$_{CAUSE}$ MARGE$_{AGENT}$ BOX$_{THEME}$ TO HOMER$_{DESTINATION}$ + *Marge dragged the box to Homer*), from which it extracts argument-structure frames (e.g., [argument1] [verb] [argument2] [argument3]). Frames that are sufficiently similar are collapsed into constructions, using an unsupervised Bayesian clustering process. This model is similar to the present simulation in its use of verb and construction semantics, which allows it to show both generalization to novel verbs and overgeneralization with subsequent retreat, and also in its use of corpus-derived verb+construction counts. An important difference is that Alishahi and Stevenson's

(2008) simulations did not investigate the relative importance of entrenchment, pre-emption and verb semantics. Neither did these authors attempt to simulate the by-verb pattern of adult grammaticality judgments. Indeed, in its present form Alishahi and Stevenson's model is unlikely to be able to do so, since – like all of the previous models discussed in this section - it does not represent verb semantics at a sufficiently fine-grained level (see p.827 for discussion).

The present article introduces a new model that instantiates the key assumptions of Ambridge and colleagues' verbal FIT account: competition between constructions based on (a) verb-in construction frequency, (b) relevance of constructions for the speaker's intended message and (c) fit between the fine-grained semantic properties of individual verbs and individual constructions (or, more accurately, their [VERB] slot). The aim is to investigate the ability of the model (a) to explain generalization to novel verbs, overgeneralization error and subsequent retreat, (b) to model the pattern of by-verb grammaticality judgments obtained in adult studies and (c) to elucidate the relative importance of entrenchment, pre-emption and verb semantics, and explore one way in which these factors might be combined into a learning model.

Method

The problem is conceptualized as one of the speaker learning, via comprehension, verb+construction mappings that allow her, in production, to select the appropriate construction, given the verb that she intends to use (in this case the PO-dative, the DO-dative or Other). This is, of course, a relatively high-level conceptualization, and one that abstracts across the many factors other than verb-level properties that determine

construction choice (e.g., information structure, the relative length of the theme and recipient NPs etc., see Bresnan, Cueni, Nikitina & Baayen, 2007). Neither does it address the issue of how either verbs or constructions are acquired in the first place (see Twomey, Chang and Ambridge, 2014, for one simulation of the acquisition of verb semantics). Nevertheless, the rather abstract and theory-neutral nature of this conceptualization renders it potentially compatible with any theoretical approach which assumes that adult speakers possess some kind of abstract knowledge of verb argument structure constructions.

All simulations used the OXlearn MATLAB package (Ruh &Westermann, 2009). The learning task was instantiated in a three-layer feed-forward backpropagation network with seven input units (representing the verb), three hidden units, and three output units (representing PO-dative, DO-dative and Other). The structure of the network is summarized in Figure 1. Both the output and hidden layers used a sigmoid activation function (learning rate 0.01), and received input from a bias unit. Seven input units were used in order to allow each verb to be represented as a vector across seven composite semantic features taken from Ambridge, Pine, Rowland, Freudenthal and Chang (2014), roughly speaking: *causing to go* (two predictors), *causing to have, speech, mailing, bequeathing* and *motion*. In this previous study, participants rated each verb for the extent to which it exhibits each of 18 semantic features relevant to the alternation, with these features condensed to seven using Principal Components Analysis (PCA). Each verb was represented in terms of its mean rating on each of these seven composite semantic features.

It is important to acknowledge that this implementation sidesteps the extremely difficult question of how learners acquire verb semantics, assuming – in effect – that learners have perfect knowledge of the semantics of every verb from the very first time

that they hear it. In fact, real-life acquisition of verb semantics no doubt requires a considerable amount of experience, and presumably proceeds at least in part on the basis of syntactic and lexical distributional information (e.g., Gleitman, 1990; Pinker, 1994; Twomey, Chang & Ambridge, 2014). However, it is important to point out that this problem is shared by all current models of the acquisition of verbs' argument structure restrictions; both the verbal models outlined in the introduction, and the computational models outlined in the previous section. Thus this shortcoming is no reason to disregard the present model in favour of its contemporaries.

Figure 1. Architecture of the network

* = Pre-emption simulations only
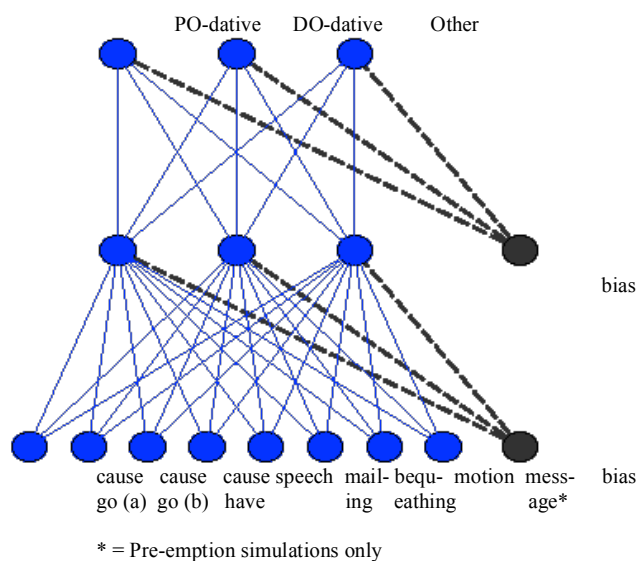
Twenty four verbs were used; the core set from Ambridge, Pine, Rowland & Chang (2012), half PO-only, half alternating (note that this first simulation did not include DO-only verbs – e.g., *bet* and *wager* - which are of very low type and token frequency, particularly in speech to children, and so constitute a marginal phenomenon).

The PO-only verbs were drawn from two semantic classes: *pull*-verbs (*pull, drag, carry, haul, lift* and *hoist*) and *shout*-verbs (*shout, screech, whisper, hiss, scream* and *shriek*). The alternating verbs were drawn from two further classes: *show*-verbs (*show, teach, ask, pose, tell* and *quote*) and *give*-verbs (*give, hand, send, mail, throw* and *toss*).

For each training trial, a verb was presented to the network, along with its target construction (i.e., the target activation of the PO-dative, DO-dative or Other output unit was set to 1, with the other two output units set to 0). Verb+construction pairs were presented to the model in proportion to the log frequency with which the verb occurred in that construction in the British National Corpus (counts taken from Ambridge et al, 2014), as shown in Table 1 below. "Other" counts include all non-dative uses of the relevant verb, including – for example – simple transitives (*He pulled the rope*) and single word utterances (e.g., *Pull!*).

Table 1. Training set

Verb	PO-dative	DO-dative	Other				
pull	4	0	8	show	5	7	10
drag	4	0	7	teach	4	6	8
carry	5	0	9	ask	3	7	10
haul	3	0	6	pose	5	3	7
lift	5	0	8	tell	4	9	10
hoist	2	0	5	quote	2	3	7
shout	3	0	7	give	7	9	10
screech	1	0	5	hand	5	6	7
whisper	3	0	7	send	7	6	9
hiss	1	0	6	mail	2	2	5
scream	2	0	7	throw	5	5	8
shriek	1	0	5	toss	3	3	6
				Total	86	66	177

Thus a single training sweep consisted of 329 verb+construction pairs (86 PO-datives, 66 DO-datives and 177 Other constructions). The overgeneralization pressure on the model arises from the fact that half the verbs it encounters activate both the PO- and DO-dative output units (though only one or the other on any given trial), while the remainder activate only the PO-dative unit (with varying frequency).

For each test trial, the frozen model was presented with a verb - either a familiar verb from the training set or a novel verb (described below) - and the corresponding activation of the DO-dative output unit recorded. The activation of this output unit is taken as the model's "grammaticality judgment" for a DO-dative sentence with the relevant verb. The model's judgments were compared against those obtained from adult participants (from Ambridge et al, 2012). This method is preferable to simply investigating the model's ability to learn the training set to some error criterion (which is trivial, given the present set-up). It is important to emphasize that the model did not receive any information regarding participants' grammaticality judgments; as described above, target activations of output units were determined solely on the basis of corpus frequency.

Novel verbs were created in order to test the model's ability to generalize; that is, to determine the grammaticality or otherwise of previously-unseen verbs in the DO-dative construction on the basis of their semantics. Ambridge et al (2012) found that adults displayed this ability, though children aged 5-6 and 9-10 did not. Novel verbs were created by averaging across the semantic ratings for all of the verbs in the relevant semantic class, excluding the target verbs. This resulted in the creation of four novel verbs, two PO-only (novel *pulling* and novel *shouting*), two alternating (novel *showing* and novel *giving*). Ambridge et al (2012) found that adults rated DO-dative uses of the former, but not the latter, as ungrammatical.

Results

   Semantics+entrenchment model. The model as described above implements

entrenchment, but not pre-emption, as all non-DO-dative uses of a particular verb,

whether PO-dative or Other, have an equal impact in causing the model *not* to activate

the DO-dative output unit for this verb (pre-emption is added to a subsequent model).

The model implements a role for verb semantics, by virtue of the fact that each verb is

represented as a vector of seven semantic feature scores. The model was trained for

100,000 sweeps (each consisting of 329 verb+construction pairs) and its output

recorded every 10,000 sweeps. All results presented here and subsequently average

across ten runs of the model with different random seeds. Figure 2 shows the familiar

and novel-verb results for the semantics+entrenchment model, averaging across the six

verbs in each class.

Figure 2. Semantics+Entrenchment model
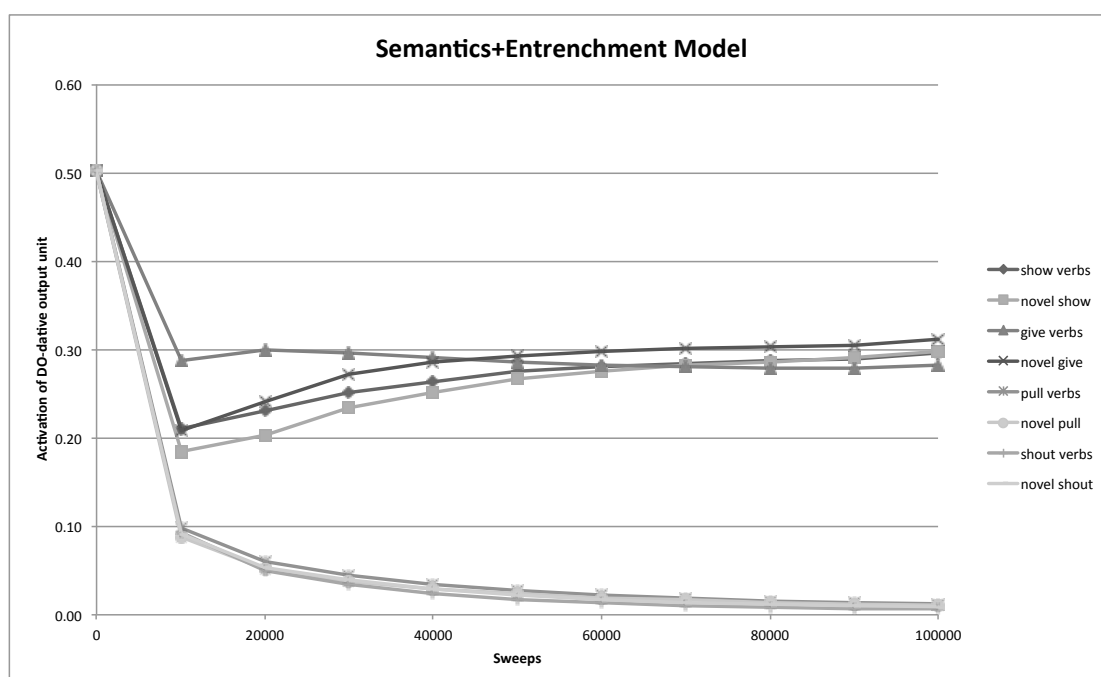
The model rapidly learns that the DO-datives are acceptable (i.e., to activate this output unit) for the *show* and *give* verbs, but not the *pull* and *shout* verbs. (The reason that the activation of the DO-dative output unit drops to around 0.3 even for verbs that are grammatical in this construction is that the model is learning that PO-dative and Other uses [e.g., transitives; single-word uses] are also possible constructions for this verb). The model also generalizes this pattern to the four novel verbs. This latter finding demonstrates one way in which it is possible for a model that includes no hard-wired discrete verb classes to show class-type generalization behaviour. A cluster plot of the hidden units (Figure 3) demonstrates that the model achieves this behaviour by forming representations in the hidden layer that map semantically-similar verbs onto the same output unit. While this finding does not demonstrate that semantic effects necessarily operate at the level of the individual verb, rather than Pinker/Levin-style verb classes, parsimony considerations would seem to suggest that such classes should not be posited, given that class-type effects can arise without them.

Figure 3. Hidden units in semantics+entrenchment model
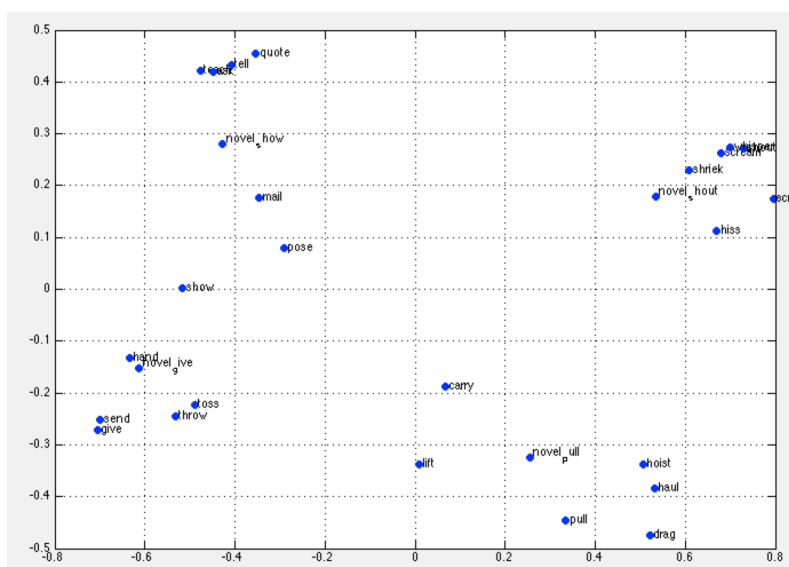
The finding that the model does not link the familiar *pull* and *shout* verbs to the DO-dative is, in one sense, trivial: Because the activation of the output units sums to 1 and these verbs activate only the PO-dative and Other units during training, it is inevitable that the model will not activate the DO-dative unit for these verbs. In another sense, however, the triviality of this finding is exactly the point: A learner that probabilistically links verbs and the constructions in which they have appeared will inevitably show an "entrenchment" effect, even while retaining the ability to generalize novel verbs into unattested constructions on the basis of their semantics; there is no need to posit entrenchment as a special dedicated mechanism.

That said, the *semantics+entrenchment* model fails in two important respects. First, unlike children, it does not display a period of overgeneralization. For the *pull* and *shout* verbs – familiar and novel alike – the activation of the DO-dative unit drops rapidly to below 0.1 within the first 10,000 sweeps. Second, at no point during learning do the model's judgments of overgeneralization errors (i.e., DO-uses of PO-only verbs) correlate with those obtained from adult participants (see Figure 4, plotted at 60,000 sweeps, for comparison with the subsequent model).

Figure 4. No correlation between model and human ratings for semantics+entrenchment model

Semantics+Entrenchment Model Predictions and Adult ratings for ungrammatical DO-datives
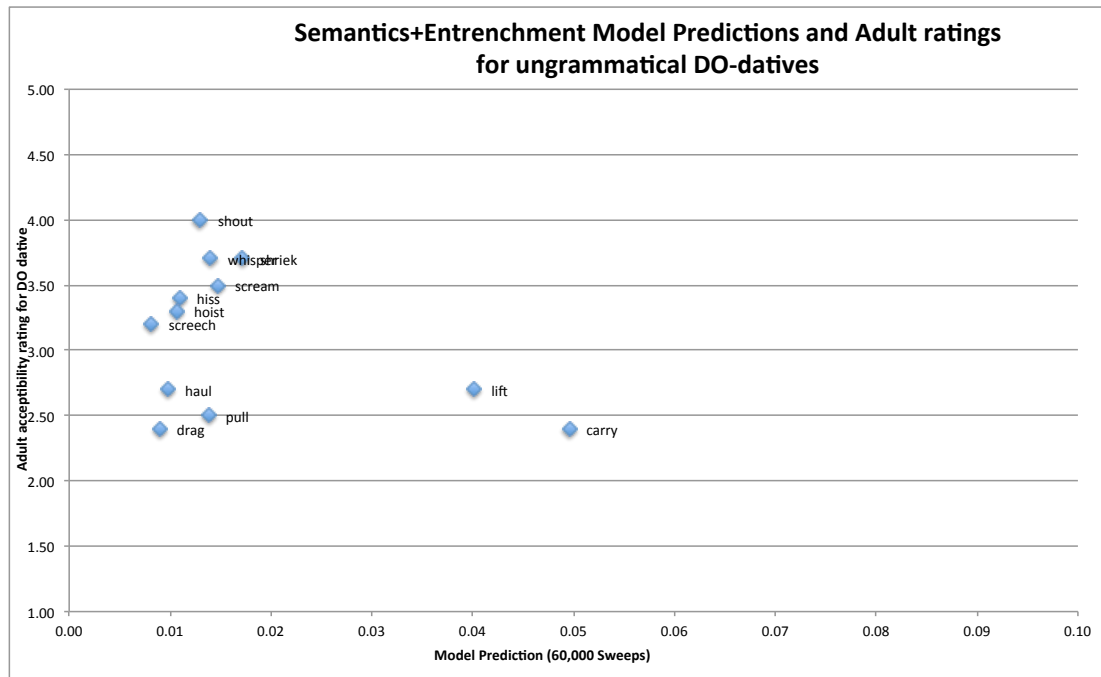
Semantics+Entrenchment+Pre-emption **model**. The pre-emption hypothesis holds that overgeneralization errors are blocked not by *any* uses of the relevant verb (as under entrenchment), but only – or, at least, especially - by uses that express the same intended meaning (or "message"). For example, the error **Marge pulled Homer the box* (*pull*+DO-dative) would be pre-empted by *pull*+PO-dative sentences (e.g., *Bart pulled the box to Lisa*), as both sentences express a three-argument "transfer" message. Such an error would not be pre-empted by simple transitives (e.g., *He pulled the rope*), one-word utterances (*Pull*!), and so on, as such sentences do not express a transfer message.

Pre-emption was instantiated in the model by adding an additional input unit to encode the message. This unit was set to 1 when the target output unit was either the PO- or DO-dative unit (= "transfer message") and 0 when the target output was Other (= "non-transfer message"). In terms of real-word learning, the assumption is that learners understand the speaker's intended message in comprehension (=the model's learning phase) and have in mind their own intended message in production (=the

model's test phase). In all other respects, including the training set, the model was identical to that outlined above.

This model (see Figure 5) addressed both of the shortcomings of the *semantics+entrenchment* model. First, in contrast to this previous model, it showed a protracted "overgeneralization" period (approximately 0-40,000 sweeps) in which verbs that been presented solely in PO-dative sentences during training (the familiar *pull* and *shout* verbs) activated the DO-dative output unit, with an activation strength similar to that yielded by the alternating verbs (the familiar *show* and *give* verbs). Presumably, this overgeneralization period is consequence of the fact that the "transfer message" unit (which was always set to 1 during testing, since a DO-dative judgment was being elicited) mapped to both the PO- and DO- output units during training. The model retreats from overgeneralization as it learns *which* particular dative unit, PO or DO, is appropriate for each verb; information that this model (like the previous model) rapidly generalizes to novel verbs, presumably on the basis of semantic overlap with familiar verbs (a later simulation tests this presumption).

Figure 5. Semantics+entrenchment+pre-emption model
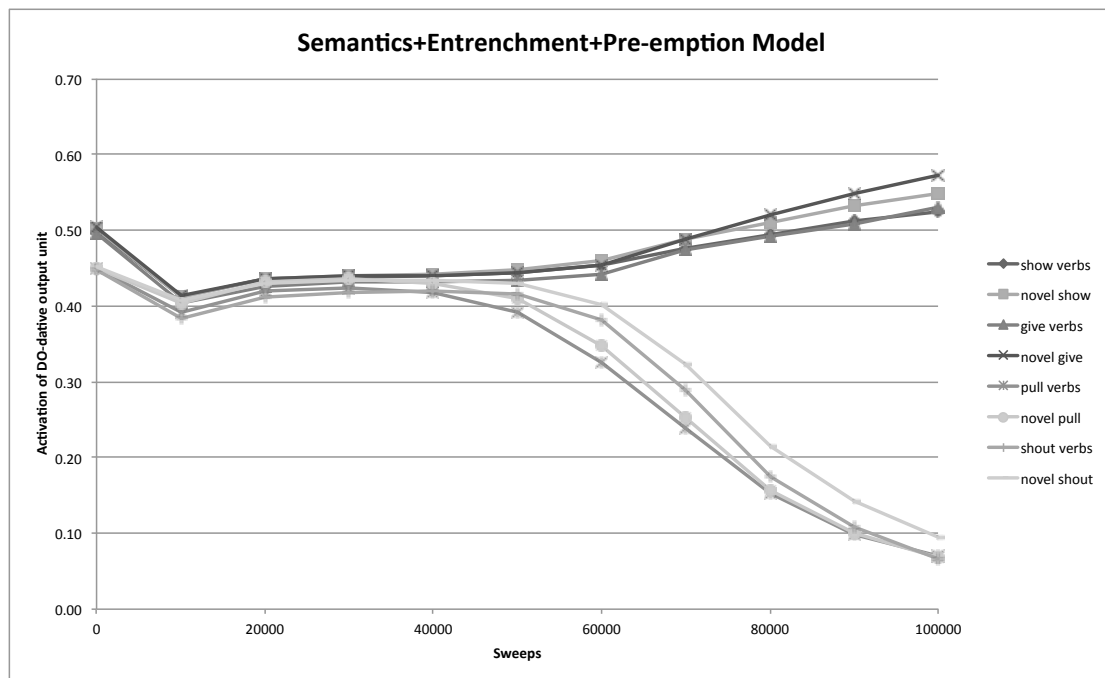
Addressing the second shortcoming of the previous model, the current model

simulated, at 5,000 and 6,000 sweeps, the by-verb pattern of adult grammaticality

judgment data for overgeneralization errors of PO-only verbs into the DO-dative

construction (r=0.66, p=0.02; r=0.68, p=0.02), see Figure 6. Beyond this point, no

significant correlations were observed, presumably because the model had over-

learned the solution, increasingly treating all verbs attested only in the PO-dative as

extremely – and equally – ungrammatical in the DO-dative.

Of course, the fact that a three-parameter model (Semantics + Entrenchment +

Preemption) outperforms a two-parameter model (Semantics + Entrenchment) should

surprise no-one. The point is that the Preemption mechanism is not a free parameter

added for no reason other than to improve coverage of the data, but rather an

implementation of a particular theoretical proposal that is well supported by previous

empirical studies with children and adults.

Figure 6. Correlation between model and human ratings for semantics+entrenchment+pre-emption model
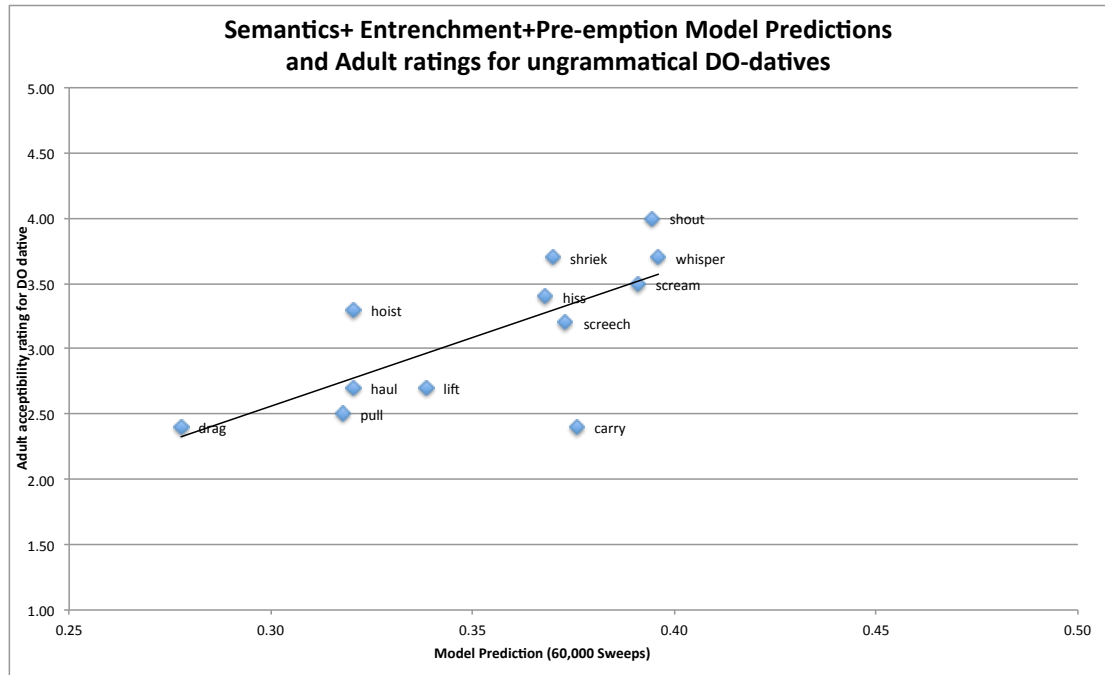
Semantics vs Pre-emption: Can pre-emption be used to learn arbitrary exceptions to semantically-based generalizations? It has often been suggested (e.g., Goldberg, 1995; 2006; Boyd & Goldberg, 2011) that pre-emption might be useful for learning exceptions to semantically-based generalizations (though, in the case of the dative, there has been some debate as to whether, given sufficiently fine-grained and probabilistic generalizations, such exceptions in fact exist; see Ambridge et al, 2014: 237). Consider, for example, a hypothetical verb that is semantically consistent with both the PO- and DO-dative (e.g., a novel *giving* or *shouting* verb) but that, for some reason, happens to appear only in the PO-dative construction[iii]. Would learners treat it as an exception (as pre-emption would predict), or would the exception be swamped by the semantic generalization?

In order to explore this question, the four novel verbs used in the *Semantics+Entrenchment+Pre-emption* simulation were added to the training set

shown in Table 1. Each was presented 10 times per sweep, **always in PO-dative**

constructions (hence they are referred to subsequently as *PO-only novel*

pull/shout/show/give). *PO-only novel pull* and *PO-only novel shout* are best thought of

as "control" verbs: Both semantics and pre-emption push the model in the direction of

rejecting the DO-dative, which it would therefore be expected to do rapidly. *PO-only*

novel shout and *PO-only novel give* instantiate the thought-experiment outlined above,

and pit semantics and pre-emption against one another. Each of these novel verbs is

semantically similar to six verbs that appear in both the PO- and DO-dative during

training; thus their semantics push the model in the direction of predicting the DO-

dative for that verb. On the other hand, both are attested with very high frequency in

the PO-dative only (10 presentations per sweep; a rate chosen to be higher than any

other verb+construction pair in the dataset). Thus pre-emption pushes the model in the

direction of rejecting the DO-dative for that verb (i.e., predicting the PO-dative

instead). This new training set was given to the *Semantics+Entrenchment+Pre-*

emption model outlined above.

Figure 7 plots these results for the novel verbs only (results for the familiar

verbs were the same as for the previous *Semantics+Entrenchment+Pre-emption*

model).

Figure 7. Semantics vs Pre-emption
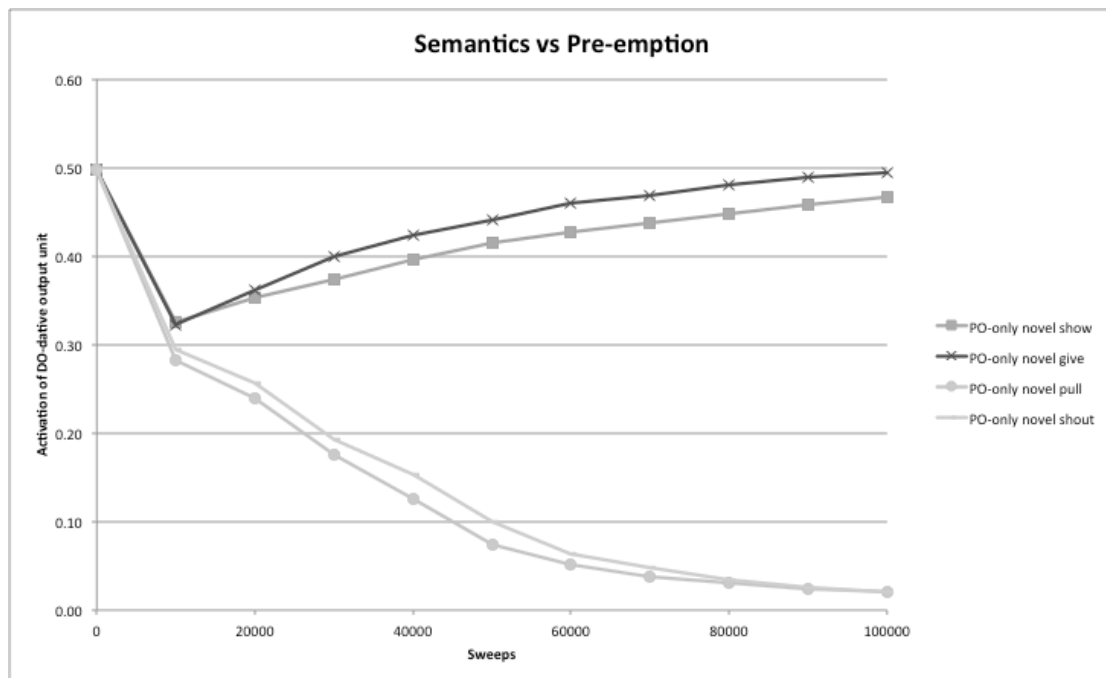
The simulation revealed that with a very high rate of pre-emption, the model is able to

learn this arbitrary exception, but only with an extremely high – perhaps implausibly

high – number of sweeps. At 10,000 sweeps (which is easily sufficient for the model to

learn to predict the behaviour of both the familiar and non-exceptional novel verbs),

the model's behaviour for these verbs appears to be determined almost exclusively by

their semantics. Subsequent testing revealed that even with one million sweeps, the

DO-dative activation for *PO-only novel give* and *PO-only novel show* had declined

only to 0.41 and 0.37 respectively. That said, give sufficient training, the model is able

to learn the exception: The DO-dative activation for both novel verbs declined to

around zero after 10 million sweeps.

Of course, to the extent that the relative weight of generalizations and

exceptions depends on precise properties of the training set, there are no doubt some

possible set-ups under which these exceptions would be more easily learnable.

Nonetheless, with a training set that broadly approximates the input to which children

are exposed, it is extremely difficult for this model at least to learn an exception, even with high levels of pre-emption. This finding is consistent with the observation that, historically, arbitrary exceptions to particular rules tend to gradually be subsumed into the generalization. For example, in the well-studied domain of the English past-tense, Liberman, Michel, Jackson, Tang & Nowak (2007) reported that of 177 irregular verbs from 9th Century old English, 79 have become regularized, and now form their past tense with –*ed*.

      Extending the Semantics+entrenchment+pre-emption model. The final set of simulations investigated whether the most successful model, which instantiated semantics, entrenchment and pre-emption, would scale up to a larger dataset: the full set of 301 dative verbs rated by adults in the study of Ambridge et al (2014), comprising 145 alternating verbs, 131 PO-only verbs and 25 DO-only verbs. Because this set was designed to be as comprehensive as possible, including every English dative verb indentified in two major reference works on the topic (Pinker, 1989; Levin, 1993), it constitutes an appropriate test of the model's ability to scale up to something like a life-sized dataset.

Table 2. Extended training set.

Verb	PO	DO	OT.	Verb				Verb			
Feed	4	4	8	Serve	3	4	8	Shunt	1	0	4
Give	7	9	10	Trade	1	0	7	Slip	2	3	7
Lease	3	2	5	Hand	5	6	7	Smuggle	2	0	5
Lend	6	5	7	Donate	4	0	6	Sneak	1	1	5
Loan	2	3	5	Contribute	5	0	8	UPS	0	0	0
Pass	5	4	9	Forward	3	2	5	Transport	4	0	6
Pay	7	6	9	Hand	5	6	7	Deliver	5	0	8
Peddle	1	0	4	Mail	2	2	5	Airfreight	0	0	1
Refund	1	1	5	Pass	5	4	9	FedEx	0	0	0
Render	3	3	7	Port	3	0	5	Courier	0	0	1
Rent	3	2	6	Post	3	0	6	Messenger	0	0	0
Repay	2	2	6	Send	7	6	9	Bash	0	0	5
Sell	6	5	9	Shift	4	0	7	Bat	0	0	5
				Ship	3	0	6	Bunt	0	0	0

Cast	2	3	7	Push	5	0	8	Deny	5	6	8
Catapult	1	0	4	Schlep	0	0	1	Bet	0	3	7
Chuck	1	2	6	Shove	2	1	6	Bill	0	1	5
Flick	2	2	6	Tote	0	0	3	Charge	3	5	8
Fire	1	0	7	Tow	2	0	5	Fine	0	4	6
Fling	3	2	6	Tug	2	0	6	Mulct	0	0	2
Flip	2	0	5	Drop	3	4	8	Overcharge	0	0	3
Hit	3	0	8	Hoist	2	0	5	Save	2	5	8
Hurl	2	0	6	Lift	5	0	8	Spare	0	4	6
Kick	3	0	7	Lower	4	0	7	Tax	0	0	6
Lob	1	1	4	Raise	5	0	9	Tip	2	1	6
Loft	0	0	3	Bring	7	6	9	Undercharge	0	0	1
Nudge	1	0	5	Take	7	6	11	Wager	0	0	4
Pass	5	4	9	Advance	2	3	7	Ask	3	7	9
Pitch	1	0	6	Allocate	4	4	7	Cite	1	0	7
Punt	0	0	3	Allot	3	2	5	Preach	2	0	6
Shoot	2	4	8	Assign	5	4	6	Quote	2	3	7
Shove	2	1	6	Award	4	5	7	Read	4	5	9
Slam	1	0	6	Bequeath	3	2	5	Relay	3	0	5
Slap	1	0	6	Cede	3	0	4	Show	5	7	10
Sling	0	0	5	Concede	3	2	6	Teach	4	6	8
Smash	1	0	6	Extend	4	0	8	Tell	4	9	10
Tap	1	0	7	Grant	5	6	8	Write	5	0	9
Throw	5	5	8	Guarantee	3	4	7	Pose	5	3	7
Tip	2	1	6	Issue	5	3	8	Spin	1	2	7
Toss	3	3	6	Leave	6	5	10	Explain	5	0	9
Poke	0	0	6	Offer	6	7	9	Announce	3	0	8
Blast	1	0	6	Owe	6	6	7	Describe	4	0	9
Propel	2	0	5	Promise	3	5	8	Admit	4	0	8
Release	3	0	8	Vote	2	2	8	Confess	3	2	6
Alley-oop	0	0	0	Will	1	1	6	Repeat	3	0	8
Lob-pass	0	0	0	Yield	3	3	7	Declare	3	0	8
Bounce	0	0	6	Refer	5	0	8	Recount	2	0	5
Float	1	0	7	Forward	3	2	5	Cable	1	2	4
Move	5	0	9	Guarantee	3	4	7	Email	0	1	2
Roll	2	0	7	Reserve	1	0	7	Fax	2	2	5
Slide	2	2	7	Recommend	4	0	8	Modem	0	0	0
Carry	5	0	9	Permit	2	4	7	Netmail	0	0	0
Drag	4	0	7	Cost	2	6	8	Phone	1	2	7
Haul	3	0	6	Spare	0	4	6	Radio	0	0	3
Heave	2	1	6	Envy	0	4	5	Relay	3	0	5
Heft	0	0	3	Begrudge	1	3	3	Satellite	0	0	0
Hoist	2	0	5	Refuse	3	4	8	Semaphore	0	0	2
Kick	3	0	7	Ask	3	7	9	Sign	2	0	8
Lug	1	0	4	Save	2	5	8	Signal	3	1	6
Pull	4	0	8	Forgive	1	4	7	Telephone	2	0	7

Word				Word				Word			
Telecast	0	0	1	Mumble	1	0	5	Allege	0	0	7
Telegraph	1	0	3	Murmur	2	0	7	Announce	3	0	8
Telex	0	0	4	Mutter	3	0	7	Articulate	2	0	6
Wire	0	1	5	Purr	0	0	4	Assert	0	0	7
Wireless	0	0	1	Rage	0	0	5	Blab	1	0	2
Babble	0	0	4	Rasp	0	0	5	Blurt	0	0	5
Bark	1	0	6	Roar	1	0	6	Claim	0	0	9
Bawl	0	0	4	Scream	2	0	7	Communicate	4	0	7
Bellow	1	0	5	Screech	1	0	5	Confess	3	2	6
Bleat	0	0	4	Shout	3	0	7	Confide	3	0	5
Boom	0	0	5	Shriek	1	0	5	Convey	4	0	7
Bray	0	0	4	Sing	3	0	8	Declare	3	0	8
Burble	0	0	4	Snap	1	0	7	Mention	5	0	8
Cackle	0	0	4	Snarl	0	0	5	Note	1	0	8
Call	4	0	9	Snuffle	0	0	4	Observe	0	0	8
Carol	0	0	2	Splutter	0	0	5	Proclaim	2	4	6
Chant	0	0	5	Squal	0	0	2	Propose	2	0	8
Chatter	0	0	5	Squawk	0	0	4	Reiterate	1	0	6
Chirp	0	0	3	Squeak	0	0	5	Relate	0	0	8
Cluck	1	0	4	Squeal	0	0	5	Remark	1	0	7
Coo	0	0	3	Stammer	0	0	4	Report	5	0	9
Croak	0	0	5	Stutter	0	0	4	Reveal	4	0	8
Croon	0	0	4	Thunder	0	0	5	Say	6	0	11
Crow	0	0	4	Tisk	0	0	0	State	1	0	8
Cry	2	0	8	Trill	0	0	3	Suggest	3	0	9
Drawl	0	0	3	Trumpet	0	0	4	Doubt	0	0	7
Drone	0	0	4	Twitter	0	0	3	Question	0	0	7
Gabble	0	0	4	Wail	0	0	5	Credit	1	0	6
Gibber	0	0	3	Warble	0	0	3	Entrust	4	0	5
Groan	0	0	6	Wheeze	0	0	4	Furnish	2	0	6
Growl	0	0	5	Whimper	0	0	4	Issue	5	3	8
Grumble	0	0	5	Whine	0	0	5	Leave	6	5	10
Grunt	0	0	5	Whisper	3	0	7	Present	6	0	8
Hiss	1	0	6	Whistle	1	1	6	Provide	6	0	9
Holler	0	0	3	Whoop	0	0	4	Serve	3	4	8
Hoot	0	0	4	Yammer	0	0	1	Supply	5	3	8
Howl	1	0	5	Yap	0	0	4	Trust	3	0	7
Jabber	0	0	3	Yell	2	0	6	Reward	0	0	6
Lilt	0	0	3	Yelp	0	0	4	Honour	0	0	6
Lisp	0	0	3	Yodel	0	0	2	Bestow	0	0	5
Moan	0	0	6	Admit	4	0	8				

This model was trained in exactly the same way as for the previous version of the

Semantics+entrenchment+pre-emption simulation, but with this larger training set. The

model again showed a good fit to the adult data (r=0.54, p<0.001; see Figure 8),

reaching asymptote at around 1,000 sweeps; considerably sooner that previous model

(which is to be expected given the much larger dataset).

Figure 8. Correlation between model and human ratings for

semantics+entrenchment+pre-emption model with extended dataset (301 verbs).

To summarise, the most successful model – the semantics+entrenchment+pre-

emption model – was successful in (a) simulating an overall overgeneralization-then-

retreat pattern (b) predicting the correct dative argument structure for novel verbs on

the basis of their semantics and (c) modeling the fine-grained pattern of by-verb

grammaticality judgments observed in adult studies, including a large scale study that

included almost all English dative verbs.

Discussion

A central question in the cognitive sciences is how children build linguistic representations that allow them to generalize verbs from one construction to another (e.g., *The boy gave a present to the girl* → *The boy gave the girl a present*), whilst appropriately constraining those generalizations to avoid nonadultlike errors (e.g. *I said no to her* → **I said her no*). Indeed, for the many children who pass through a stage in which they produce such errors, the question is how they learn to retreat from them, given the absence of consistent evidence regarding which of their utterances are ungrammatical.

Recently, a consensus has begun to emerge that children solve this "no negative evidence problem" (Bowerman, 1988), using a combination of statistical learning procedures such as entrenchment (e.g., Theakston, 2004) and pre-emption (e.g., Boyd & Goldberg, 2011), and learning procedures based on verb semantics (e.g., Ambridge et al, 2008, 2009, 2011, 2012a, 2012b, 2014). Despite this emerging consensus, there have been few attempts to propose a unitary account that combines all three approaches. One exception is the FIT account (Ambridge et al, 2011) which argues for competition between constructions based on (a) verb-in construction frequency, (b) relevance of constructions for the speaker's intended message and (c) fit between the fine-grained semantic properties of individual verbs and individual constructions.

The present study demonstrated that a simple connectionist model that instantiates this account can not only simulate the overall pattern of overgeneralization then retreat but also use the semantics of novel verbs to predict their argument structure (as in the human studies of Ambridge et al, 2008, 2009, 2012b; Bidgood et al,

2014) and predict the by-verb pattern of grammaticality judgments observed in adult studies (Ambridge et al, 2012b).

Although the model used is computationally extremely simple, there is an important sense in which this is its greatest strength. The success of the model suggests that statistical learning effects such as entrenchment and pre-emption need not make use of sophisticated Bayesian or rational learner algorithms to compute an inference from absence. Rather, these effects arise naturally from a learning mechanism that probabilistically links verbs to competing instructions. Similarly, semantic effects need not rely on an explicit procedure for semantic class formation (e.g., Pinker, 1989), but fall naturally out of a model that learns which bundles of semantic features ("verbs") are predictive of which constructions.

Nevertheless, it is important to acknowledge the ways in which the present simulations considerably oversimplify the task facing real learners. First, the precise semantic properties of individual verbs are known from the start. For child learners, acquiring verb meanings is a notoriously difficult task (Gillette, Gleitman, Gleitman, & Lederer, 1999), and one that presumably proceeds mostly in parallel with learning verb argument structure constructions (e.g., Twomey et al, 2014). Second, the simulated learner is assumed to have already abstracted the necessary verb argument structure constructions (e.g., PO- and DO-dative) from the input, and to be able to correctly recognize all further instances of these constructions in the input (though the semantic characteristics of these constructions are learned during the simulation). For real learners, acquiring verb argument structure constructions is an extremely difficult task; indeed, there are very few proposals for how this might be done (though see Tomasello, 2003; Alishahi & Stevenson, 2008). Finally, the model does not – unlike both real learners and more sophisticated computational models (e.g. Chang, 2002;

Chang et al, 2006) – produce sentences as sequences of temporally ordered words. There is quite a leap to be made from (a) knowing the verb+argument structure combination that one intends to use to (b) producing a well-formed sentence.

Indeed, under many accounts, verb argument constructions are not, in fact, seen as entities that are abstracted from the input, then stored for subsequent retrieval. Exemplar-based accounts (e.g., Langacker, 2000; Bybee, 2013) propose that learners store nothing more than individual exemplars (here, sentences), and that the notion of – for example – "using a DO-dative construction" – is simply a shorthand way of referring to a process of online generalization across stored DO-dative sentences that meet some criterion (e.g., similarity to the intended message). In order to instantiate such accounts computationally, we will need considerably more sophisticated models that are able to use both semantic and distributional commonalities to abstract, on the fly, across stored exemplars in a way that yields something like conventional verb argument-structure constructions.

In the meantime, the present findings suggest that the traditional conceptualization of entrenchment, pre-emption and the formation of semantic generalizations as rival "mechanisms" may be unhelpful. Rather, all three are best thought of as labels for *effects* that fall naturally out of a learning mechanism that probabilistically associates particular verbs (where each verb is a collection of semantic feature) and particular argument structure constructions. The computational model outlined in the present article constitutes one possible account of how this can be done.

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Footnotes

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[i] The acronym captures the account's emphasis on the importance of the *Fit* between *Items* and (construction) *Templates* (in this case, with regard to semantics).

[ii] A fourth factor – overall construction frequency – may also be important. That is, all else being equal, a speaker is more likely to select a higher frequency construction (e.g., an active transitive) than a lower frequency alternative (e.g., the passive). The present simulations do not explore this factor, but it may be necessary to explain, for example, why some alternations attract higher error rates than others.

[iii] Verbs such as *contribute* and *donate* are examples of such verbs (**I donated/contributed the appeal some money* vs *I donated/contributed some money to the appeal*). However, there is empirical evidence (Ambridge et al, 2012; 2014) that speakers treat such verbs as conforming to a morphophonological generalization not instantiated in the present model. Thus such verbs do not necessarily constitute exceptions to generalizations that must be learned by pre-emption alone.