An ACT-R Model of Sentence Sorting with Argument Structure Constructions

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Based on the results of a sorting task involving verbs and grammatical patterns, Bencini & Goldberg (2000) argue that "argument structure constructions are directly associated with sentence meaning." We explore this hypothesis by attempting to replicate their results using a nonhuman categorizer: a cognitive model based on ACT-R (Anderson & Lebiere 1998). The model replicated the sentence-sorting behaviors of Bencini & Goldberg's subjects, but did so using formal cues alone. This outcome suggests that the subjects in the Bencini & Goldberg study were not necessarily attending to constructional meaning, and lends support to Bock's (1986) conclusions regarding syntactic priming: subjects' similarity judgments are as likely to be based on syntactic form alone as they are to involve syntax-semantic mapping.

1. Introduction

This paper investigates whether argument structure patterns play a role in sentence interpretation. Bencini and Goldberg argue, based on two experiments described in their paper, that "argument structure constructions are directly associated with sentence meaning" (Bencini & Goldberg 2000). This constructional approach differs from other approaches, specifically, lexical and multiple-sense approaches. A lexical approach posits that syntactic and semantic information are encoded entirely on the verb. A multiple-sense approach views different verb constructions as different representations for that verb.

Bencini and Goldberg conducted experiments in which subjects sorted sixteen sentences by meaning. The sixteen sentences were comprised of four different verbs, and four different constructions. Based on previous sorting experiments (Regehr & Brooks 1995), it would be expected that subjects would sort on a single dimension—by verb. However, Bencini and Goldberg discovered that subjects took both verb and construction into account when considering sentence meaning.

We explore this hypothesis by attempting to replicate Bencini and Goldberg's results using a nonhuman categorizer: a cognitive model based on

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ACT-R (Adaptive Control of Thought-Rational) (Anderson & Lebiere 1998). Experiments were conducted with the ACT-R model following Bencini and Goldberg's experiment method. The first experiment resulted in sorts that indicate that the model was sorting primarily by verb. The second experiment resulted in a divided strategy, one that was neither close to a verb sort, nor close to a constructional sort.

This paper is structured as follows: In section 2, the Bencini and Goldberg experiment is described, including a comparison of the constructional model to the lexical and multiple-sense approaches. Section 3 details sorting strategies often employed by subjects: single-dimension and family resemblance sorts. Section 4 provides a basic description of the ACT-R cognitive modeling framework. In section 5, the ACT-R model created for this experiment is described. Section 6 presents the experiment results. Finally, section 7 discusses the results of the ACT-R model experiments in comparison to the findings of Bencini and Goldberg, and presents future issues for consideration.

2. The Bencini and Goldberg Experiment

Bencini and Goldberg conducted experiments to "test whether argument structure constructions play a role in determining sentence meaning" (B&G 2000: 643). A verb's argument structure describes the number and types of participants defined for that verb. For example, in sentence (1) below, the verb 'sing' has one argument, Mary, an actor.

(1)Mary sings.

An argument structure construction is a verb-level grammatical pattern that links semantic roles to grammatical roles (Goldberg 1995, Michaelis & Ruppenhofer 2001). Event-structure meanings classically viewed as the output of lexical rules, e.g., the ditransitive or 'double object' pattern, are instead viewed as construction meanings. The meaning of a sentence arises from the integration of the verb's meaning and the construction's meaning as, e,g., *She sliced the tomatoes into the salad* denotes the means by which the agent of the sentence effected the caused motion event denoted by the construction (Bencini & Goldberg: 642).

This construction-based model used by Bencini and Goldberg is based on Construction Grammar. Construction Grammar is a theory that looks at all components of language—core and non-core language uses, and does not have a strict division between the lexicon and syntax, or between semantics and pragmatics (Goldberg 1995: 7). This theory is committed to treating "all types of expressions as equally central to capturing grammatical patterning (i.e. without assuming that certain forms are more 'basic' than others) and in viewing all dimensions of language (syntax, semantics, pragmatics, discourse, morphology,

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phonology, prosody) as equal contributors to shaping linguistic expressions" ("Construction Grammar").

An alternative approach to the construction model is the lexical projection model. This approach theorizes that the verb is the primary source of sentence comprehension—it holds syntactic and semantic information. Different uses of the same verb are derived by using lexical rules or transformations. For example, the ditransitive/prepositional alternation is produced by a lexical rule that transforms semantic structure. Pinker suggests that this rule takes an input verb "with the semantics 'X CAUSES Y TO GO TO Z' and produces the semantic structure 'X CAUSES Z TO HAVE Y'" (Goldberg 1995: 8). One problem with this approach is that there are ditransitive expressions that do not have a corresponding prepositional expression, and vice versa:

(2)a. Jane refused Fred a kiss. (Goldberg 1992)
b. *Jane refused a kiss to Fred.

(3)a. I said my prayers to my mother.
b. *I said my mother my prayers.

Another problem with the lexical approach is that some verbs do not entail that Z has Y as illustrated by the examples in (4):

(4)a. Rose flipped the pancake to Cleo, but it landed on the floor.
b. Ron threw the ball to Cal, but he didn't get it.

In both examples, the entailment that Z has Y is defeased: Cleo does not have the pancake, nor does Cal have the ball.

Another approach is a theory that suggests different verb senses for a single verb. Bencini & Goldberg refer to this theory as the multiple-sense approach. Rappaport Hovav and Levin describe this approach by explaining "variations in a verb's meaning are because of a verb's basic semantic classification being expanded" (Rappaport Hovav and Levin 1998: 104). A verb has multiple lexical semantic templates—or event structure templates (Rappaport Hovav and Levin 1998: 107). These multiple templates account for multiple verb meanings. For example, these are a few of the variations of the verb 'sing':

(5)a. Darla sang.
b. Darla sang the song.
c. Darla sang the song to Charlie.
d. Darla sang the song across the ocean.
e. Darla sang the song loudly.

These different uses, or senses, of the verb are captured by different event structure templates.

One benefit to using the constructional approach is multiple (usual and unusual) senses of verbs are avoided. Consider sentence (6):

(6)Sam sneezed the napkin off the table. (Goldberg 1995: 29)

The verb 'sneeze' is typically an intransitive verb, however, based on the above example, a lexical approach would have to suggest that 'sneeze' takes three arguments. A constructional approach, on the other hand, would argue that the construction itself contributes the change in meaning, not the individual verb.

Another benefit to associating sentence meaning to both the verb and the construction is seen with a sentence that contradicts the meaning of the construction, as in (7):

(7)Pat ignored Chris.

In (7), the transitive construction is X ACTS on Y. However, the meaning of the sentence is clearly that Pat (X) has nothing to do with Chris (Y). The verb 'ignore' negates the transitive construction. According to Goldberg (1997), "the meaning of the verb is integrated with the meaning of the construction, resulting in entailments that neither the verb or the construction have independently." Without the relationship between verb and construction, the meaning of the sentence would be based solely on the verb, disregarding the meaning provided by the construction.

In the Bencini and Goldberg study, subjects were asked to sort 16 sentences into four piles by meaning; these sentences combined four different verbs (*throw, get, slice, take*) with four different constructions (*transitive, ditransitive, caused motion, resultative*). Table 1 lists the experiment stimuli. Our experiment uses the same stimuli.

In Bencini and Goldberg's first experiment, 17 participants were tested as a group and were asked to write a paraphrase for each sentence. They were then asked to sort the sentences into four piles based on the sentence meaning. The participants were also told that the same words in sentences can have different meanings, as seen in the examples "kick the bucket" versus "kick the dog" (Bencini & Goldberg 2000). Of the 17 participants, 7 sorted by construction alone, and 10 used a mixed sort strategy. None of the participants sorted only by verb. Because the experiment instructions could have influenced the participants' avoidance of verb only sorts, Bencini & Goldberg conducted a second experiment.

The second experiment involved the same number of participants. The procedure was modified slightly as follows: participants were tested individually, there was no mention of the same words having different meanings, and participants were asked to explain their grouping strategies after they completed the task. In this experiment, 7 sorted by verb, 6 by construction, and 4 used a mixed sort strategy. Bencini and Goldberg analyzed the explanations given by

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the participants to determine if they were attending to sentence meaning or surface cues. One example of an explanation given for a ditransitive sentence is: "Here one person is doing something for another person" (Bencini & Goldberg 2000). Based on that explanation, the participant could have been attending to the overall sentence meaning. However, all of the ditransitive stimuli involved two people, so participants could have been paying attention to surface cues only.

Table 1: Experiment Stimuli

Verb	Transitive	Ditransitive	Caused Motion	Resultative
throw	(8) Anita threw the hammer.	(12) Chris threw Linda the pencil.	(16) Pat threw the keys onto the roof.	(20) Lyn threw the box apart.
get	(9) Michelle got the book.	(13) Beth got Liz an invitation	(17) Laura got the ball into the net.	(21) Dana got the mattress inflated.
slice	(10) Barbara sliced the bread.	(14) Jennifer sliced Terry an apple.	(18) Meg sliced the ham onto the plate.	(22) Nancy sliced the tire open.
take	(11) Audrey took the watch.	(15) Paula took Sue a message.	(19) Kim took the rose into the house.	(23) Rachel took the wall down.

Although previous results (e.g., Regehr & Brooks 1995) lead to the prediction that subjects would perform unidimensional sorts (i.e., by verb), the results of the Bencini & Goldberg experiment suggested that subjects took both verb and construction semantics into account. There is, however, an alternate interpretation of their results: subjects were not attending to event-structure semantics, but were instead performing pattern matching. In order to determine which of these two construals is correct, an ACT-R model was created that uses random selection and pattern matching to sort sentences.

3. Typical Sorting Strategies

While this experiment primarily examines whether subjects attend to verb and construction semantics or surface cues, a second but related question is how do subjects decide to categorize sentences: what four piles are considered, and which strategies are selected?

When subjects are asked to categorize a group of objects with no feedback or instructions, the task is called category construction (also "free sorting" or "free classification") (Milton & Wills 2004: 407). The task described in this paper is a modification of category construction, as the ACT-R model is required to create four piles.

In determining the heuristics to encode in the model, literature about category construction was reviewed. There are two basic methods employed by subjects to sort objects into categories: unidimensional or family resemblance. A unidimensional, or single dimension, sort occurs when a subject picks one attribute or feature about the stimuli, and creates categories based on that attribute. A family resemblance sort occurs when the subject identifies a number of dimensional values that the objects have in common. This is "a sort pattern in which one prototype and all of its derived one-aways are placed in one category" (Regehr & Brooks 1995: 349).

In one set of experiments, it was found that the experiment procedure influenced how the subjects sorted sentences. A match-to-standards procedure reduced the use of unidimensional sort, and produced a family resemblance sort. This procedure displayed objects one pair at a time to subjects, and prevented subjects from viewing the entire array of objects at one time. Regehr and Brooks speculate that the "tendency toward family resemblance sorting seems to be a function of the fact that participants were focused on pairwise comparisons of objects" (1995: 355). In their experiments, they discovered that a full stimulus array discourages family resemblance sorting. In other words, by showing subjects all of the objects to sort, the subjects would not choose to sort by family resemblance, but by a single dimension.

However, Milton and Wills (2004) found that a match-to-standards procedure does not always produce a family resemblance sort. In their experiments, they determined that both procedure and experiment stimuli impact the sorting method chosen by subjects. These findings indicate that it is not necessarily clear which sorting method the procedure and stimuli chosen for this experiment would produce: a unidimensional (verb-based) or family resemblance (construction-based) sort.

We conducted a small, informal investigation to determine heuristics people employ when presented with the sentence-sorting task. Ten subjects were asked to sort the sentences into four piles based on sentence meaning. No other instruction was provided. Three subjects sorted by verb. Two subjects sorted by construction. The other five subjects used mixed sorts. The two constructions that subjects seemed to easily identify are the ditransitive and the resultative constructions. One subject mentioned that the ditransitive sentences all involved two people. These anecdotal results are confirmed by Bencini and Goldberg's results—the ditransitive is the easiest construction to identify. Also, it appeared that the caused motion and resultative constructions were occasionally grouped together, indicating that they were understood by subjects to be similar. Bencini and Goldberg also confirm that these two constructions are closely related.

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Based on anecdotal evidence and Bencini and Goldberg's results as described in the above paragraph, two mixed sorting strategies were created for the ACT-R model. These strategies are discussed in Section 5 below.

4. A Brief Description of ACT-R

ACT-R is a cognitive modeling framework—it is a theory of human cognition. The current version of ACT-R (ACT-R 5.0) is based on over 20 years of work, and many previous versions of the theory; therefore, a very brief description of ACT-R is provided here. ACT-R has three primary components: modules, buffers, and a pattern matcher. There are two kinds of modules: perceptual-motor and memory. The perceptual-motor modules handle how the model interacts with the world via visual, auditory, or motor mechanisms. The memory module consists of declarative memory and procedural memory. Declarative memory is knowledge that we can articulate to others, represented by chunks. The following is a chunk used for this experiment:

```
(chunk-type meaning word type)
```

The statement declares a chunk called *meaning* with two slots, *word* and *type*. A slot is an attribute of the chunk, and the values of the slots define the chunks. The meaning chunk was used to encode the experiment stimuli, with each word encoded. For example:

```
(hammer ISA meaning word "hammer" type object)
```

Procedural memory represents what we know to do with the declarative memory, and is represented by productions. A production consists of a series of buffer tests, then of a series of buffer transformations. The buffer tests are one of the ways ACT-R determines how to choose a production. The following is a production used for this experiment:

```
(P process-first-noun
  =goal>
    ISA          comprehend-sentence
    agent        nil
    action       nil
    object1      nil
    object2      nil
    word         =word
    state        read
  =retrieval>
    ISA          meaning
    word         =word
```

```
==>
  =goal>
    agent       =retrieval
    word        nil
    state       find)
```

The production is called *process-first-noun*, and can be translated as follows:

If the goal is

to comprehend the sentence

the model is reading

and agent, action, object1, object2 are nil

and word is not nil

AND, the retrieved chunk has the same value

as word

Then

change the goal by setting agent to the

retrieved word

read the next word (set the state to find)

ACT-R uses a number of buffers that collectively represent the current state of the model. The goal buffer represents where the model is in completing the current task. The retrieval buffer, shown in the above production, contains chunks that have been retrieved from declarative memory. There are additional buffers for storing information obtained from visual and auditory channels, but since these buffers do not directly apply to this experiment, they are not described here. Based on the current state of the buffers, the pattern matcher determines which productions may execute, thus causing the buffer contents to potentially change. For a more detailed description of the ACT-R framework, refer to Anderson and Lebiere (1998).

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5. The Sentence Sorting ACT-R Model

The ACT-R model for this experiment was created using ACT-R 5.0[1]. Conceptually, the model represents a human performing the sorting experiment. The model starts with the sentence words encoded in declarative memory. These are the words that match the agent, verb, object, and oblique portions of the experiment stimuli listed in Table 1. The words "the," "a," and "an" are skipped because they are not necessary for this experiment. The model runs in two phases. The first phase reads all sixteen sentences, creating chunks for each sentence and storing those chunks in memory. The ACT-R model uses a very simple parsing mechanism to construct sentence chunks. A sentence chunk has the following slots:

- <u>agent:</u> the first word in the sentence, corresponding to the subject;
- <u>action:</u> the second word in the sentence, corresponding to the verb;
- <u>object1:</u> the third word in the sentence (ignoring *a*, *an*, and *the*);
- <u>object1-type:</u> the type of the object is encoded in declarative memory to indicate animate objects;
- <u>object2:</u> the fourth word in the sentence (the second object);
- <u>preposition:</u> the preposition in the sentence;
- <u>category:</u> the selected pile to place the sentence;
- <u>sort-strategy:</u> the sort strategy chosen by the model (verb, construction, or mixed)
- <u>purpose:</u> study or categorize;
- <u>word:</u> the current word being read by the model;
- <u>state:</u> the current state of the model, used to direct production execution.

Because some slots are empty depending on the sentence, productions look for either empty slots, or a combination of empty and full slots to sort the sentences. This strategy is discussed below.

After all sixteen sentences are read, the word "categorize" is shown to the model. At this point, the model randomly picks one of the three sorting strategies (verb, construction, or mixed). The three sorting strategies are represented by three individual productions; each has a random chance of being selected. The sorting strategy is stored on each sentence chunk, and the second phrase starts. The model reads the sixteen sentences again, and sorts each sentence into one of four piles using the chosen sorting strategy.

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1 ACT-R 5.0 is freely-available software from Carnegie Mellon University, http://act-r.psy.cmu.edu/

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The verb sorting strategy matches the contents of the action slot to a verb. There are four productions that comprise the verb sort. The verbs are sorted into four piles as follows:

- Pile 1: throw
- Pile 2: get
- Pile 3: slice
- Pile 4: took.

The construction sorting strategy consists of four productions for each construction. Each production sorts the sentences based on surface cues. The transitive production matches sentence chunks with values in the agent, action, and object1 slots, and no values in the object2 and preposition slots. This template is AGENT ACTION OBJECT1.

The ditransitive production matches sentence chunks with values in the agent, action, object1, and object2 slots. The object1 slot must be a proper noun, which is coded by a meaning type of 'animate'. The caused motion production matches sentence chunks with values in the agent, action, object1, object2, and preposition slots. Additionally, the object1 is not a proper noun. Finally, the resultative construction production is similar to the ditransitive production except that the object1 is not a proper noun. The construction sorting strategy sorts the sentences as follows:

- Pile 1: transitive
- Pile 2: ditransitive
- Pile 3: caused motion
- Pile 4: resultative.

Two different mixed sorting strategies were implemented. The first experiment's mixed sorting strategy sorts the sentences as follows:

- Pile 1: threw or get verbs
- Pile 2: slice verbs
- Pile 3: take verbs
- Pile 4: resultative construction

There are five constructions for this sorting strategy, all based on the previously discussed productions. The difference with the mixed strategy is that a combination of verb and construction productions is used, and it is possible for multiple productions to match certain sentences. When multiple productions match, a production is randomly selected. For example, sentence (23) *Rachel took the wall down* would match both the *take* verb production, and the resultative construction. The model would randomly pick the production (i.e., the pile to put the sentence in), so some runs might have sentence (23) in pile 1, and others might have the sentence in pile 4.

The second experiment uses a mixed strategy that sorts the sentences as follows:

- Pile 1: get or take verbs
- Pile 2: ditransitive construction

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- Pile 3: throw or slice verbs
- Pile 4: caused motion or resultative constructions.

This strategy uses seven productions, all of which are based on the previously discussed verb and construction productions. This strategy exhibits more randomness than the first strategy because it is possible for more sentences to match multiple productions.

6. Experiment Results

6.1. Experiment 1

Method

Participants. An ACT-R model was created and run 50 times to simulate 50 participants.

Stimuli. The sixteen sentences shown in Table 1.

Procedure. For each run, the sentences were displayed sequentially, with the model reading each sentence. This is a change from the Bencini and Goldberg procedure in two ways. First, in the Bencini and Goldberg experiment, subjects were shown all sentences at the same time. This method probably influences how subjects create categories and determine sorting methods for the sentences. To simplify the ACT-R model, it was decided to show the sentences sequentially, and to have the sorting strategy chosen randomly.

Second, Bencini and Goldberg had their subjects write a short paraphrase of each sentence to ensure the sentences were processed, and possibly to indicate comprehension. This task was omitted from this experiment because this experiment focuses on producing similar sorting results with little or no comprehension.

After reading all sixteen sentences, the word “categorize” is displayed to indicate to the model that the sorting should commence. At this point, a sorting strategy is randomly selected by the model. Random strategy selection was chosen to try to simulate real world experiments where subjects would not all necessarily choose the same sorting strategy.

Next, the same sixteen sentences were displayed sequentially again. After the model read each sentence, the model sorted the sentence into one of four piles using one of three sorting strategies: verb, construction, or mixed. As mentioned above, the verb sorting strategy sorts entirely by verb, the construction sorting strategy sorts entirely by construction, and the mixed sorting strategy classifies sentences based on verb and construction.

Results

Of the 50 runs, 15 (30%) were verb sorts, 17 (34%) were construction sorts, and 18 (36%) were mixed sorts. These results are expected because the model should have been selecting the sort strategy randomly. To analyze the mixed sorts, the verb and construction deviation scores used by Bencini and Goldberg were applied. The deviation score for a verb sort (*Vdev*) is calculated by counting the number of changes that would be made to make the sort entirely verb-based. The maximum Vdev score is 12. The deviation score for a construction sort (*Cdev*) is calculated by counting the number of changes that would be made to make the sort entirely construction-based. The maximum Cdev score is also 12. Therefore, a verb sort has a Vdev score of 0, and a Cdev score of 12, while a construction sort has a Vdev score of 12, and a Cdev score of 0. There was a single run that did not sort the sentences into four piles (the sentences were sorted into three piles). This run was omitted from the data results because there was sufficient data without it.

In examining the runs that produced mixed sorts, the Vdev values are overall closer to 0 than the Cdev values. The Cdev values are closer to 12, indicating that the mixed sorting strategy in the model is most likely biased towards a verb-based sort. The mean Vdev for the mixed sorts, or average number of changes required for the sort to be entirely verb-based, is 4.7 ($\sigma = 0.9$) The mean Cdev for the mixed sorts, or average number of changes required for the sort to be entirely construction-based, is 9.7 ($\sigma = 0.8$).

6.2. Experiment 2

Method

Participants. The ACT-R model used for Experiment 1 was modified for Experiment 2, and run 50 times to simulate 50 participants.

Stimuli. The stimuli were the same as for Experiment 1.

Procedure. The procedure for the experiment was the same as for Experiment 1. However, after examining the results from Experiment 1, the mixed sort strategy used by the ACT-R model was modified with the intent of producing lower Cdev values, i.e., biasing the sort towards a construction sort. The ditransitive construction was added to the mixed sort strategy. This construction was chosen because, according to Bencini and Goldberg, this is the easiest construction to identify. Additionally, the caused motion construction was added because this construction is closely related to the resultative construction (Bencini & Goldberg, 2000, p. 646). The modified mixed sort strategy is: Pile 1: get or take verbs, Pile 2: ditransitive construction, Pile 3: throw or slice verbs, and Pile 4: caused motion or resultative constructions.

Productions were added to the model to perform the sorting actions. As in Experiment 1, multiple productions can match a particular sentence, so the model randomly picks one to fire. For example, sentence (16) *Pat threw the keys onto the roof* could be placed in Pile 3 or Pile 4. The model randomly picks which pile to place the sentence. Also, as in Experiment 1, the model picks the sort strategy randomly from verb-based, construction-based, and mixed.

Results

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Of the 50 runs, 11 (22%) were entirely verb-based sorts, 19 (38%) were construction-based sorts, and 20 (40%) were mixed sorts. These results are not surprising as the model picks the sorting strategy at random. The same verb and construction deviation scores discussed above were calculated for the mixed sorts.

The verb and construction deviation scores for the mixed sorts were both fairly high, indicating that the sorting strategy was too divisive. In other words, it was not possible for the model to sort close enough to either a verb-based or construction-based strategy. The mean Vdev is 8.1 ($\sigma = 1.1$), and the mean Cdev is 7.3 ($\sigma = 1.2$).

7. Discussion

Bencini and Goldberg's first experiment found that subjects were more influenced by constructions than verbs. The Vdev value for their experiment is 9.8, and the Cdev value is 3.2. Their second experiment produced a Vdev value of 5.5 and a Cdev value of 5.7, indicating that sorts were divided between verb and construction strategies. In comparison, the ACT-R model used for Experiment 1 was more influenced by verbs than constructions (Vdev 4.705 and Cdev 9.764). After modifying the mixed sort strategy, the model used in Experiment 2 was divided between verb and construction sorts (Vdev 8.105 and Cdev 7.315). The high mean Vdev and Cdev values produced in Experiment 2 suggest that further modifications of the model are required. These numbers potentially indicate that it is possible to create a simulation of a subject sorting experiment, and, at least in the case of Experiment 1, produce results that seem plausible.

The model randomly chose one of three sorting strategies: entirely by verb, entirely by construction, or mixed, by verb and construction. When the model sorts by verb, it looks only at the verb in each sentence, and groups sentences with the same verb into one pile. Construction sorts use templates with checks for proper nouns and prepositions. The mixed strategy uses a combination of verb and construction sorts. Because the mixed strategy used in experiment 1 resulted in more verb sorts, it was modified for experiment 2 to bias the strategy towards construction sorts.

Currently, the ACT-R model conflates category construction and sentence sorting in phase 2. The model could be modified to separate those tasks by constructing the four categories during the first phase of sentence parsing, and using those categories for sorting during the second phase. This modification would most likely use the stored sentence chunks, as the model would need to retrieve previously seen sentences from memory to revise the categories. These changes would seem to better parallel how a human subject would approach the sorting task.

While the results presented in this paper are preliminary, they do indicate that there is much more to explore in this area. First, it would be worthwhile to compute the verb and construction spread to compare values for this experiment with those produced by Bencini and Goldberg. Second, by changing the experiment procedure to a match-to-standards procedure (one in which subjects only see two sentences at a time) it would be possible to compare an ACT-R model results with human subjects. Finally, another consideration for future experimentation is to modify the stimuli used by adding additional sentences to have a total number that is not evenly divisible by 4. By using an even number of verbs and an even number of constructions, the stimuli might encourage subjects to sort along either verb or construction.

In sum, the model replicated the sentence-sorting behaviors of B&G's subjects, but did so using formal cues alone. This outcome suggests that the subjects in the B&G study were not necessarily attending to constructional meaning, and lends support to Bock's (1986) conclusions regarding syntactic priming: subjects' similarity judgments are as likely to be based on syntactic form alone as they are to involve syntax-semantic mapping.

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