Construction-Driven Language Processing

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Abstract

Construction Grammar is an emerging linguistic theory based on the notion of *constructions*—linguistic representations of form, function and meaning. This paper describes an approach to language processing during comprehension based on the *activation*, *selection*, and *integration* of *constructions* corresponding to the linguistic input. In considering the use of constructions as the basis for language processing and representation, it becomes clear that a fully integrated representation may not in principle be possible. Instead, the representations are likely to be integrated just to the extent supported by the constructions activated by the input and selected for integration. Some implications of construction-driven language processing for Double R Theory (Ball, 2005) are also explored.

Keywords: construction grammar; constructions; natural language processing; NLP; language comprehension; activation; selection; integration; Double R Theory

Construction Grammar

Construction Grammar (Fillmore, 1988; Fillmore and Kay, 1993; Goldberg, 1995) is an emerging linguistic theory based on the notion of *constructions*. "Constructions are stored pairings of form and function, including morphemes, words, idioms, partially lexically filled and fully general linguistic patterns…any linguistic pattern is recognized as a construction as long as some aspect of its form and function is not strictly predictable from its component parts" and even fully predictable constructions may be stored "as long as they occur with sufficient frequency" (Goldberg, 2003:219). A classic example of a construction is the *transitive verb clause* consisting of a *subject*, *verb* and an *object* as exemplified by "the man$_{subject}$ hit$_{verb}$ the ball$_{object}$". A less common construction is the *caused-motion* construction as exemplified by "she$_{subject}$ sneezed$_{intrans\text{-}verb}$ the napkin$_{object}$ off the table$_{direction}$" (Goldberg, 1995). The caused-motion construction is interesting in that a verb that is normally *intransitive* as exemplified by "she sneezed" occurs with an object "the napkin" and directional prepositional phrase "off the table". Many normally intransitive verbs can occur in this construction. (An alternative viewpoint is that the caused-motion construction is integrated with a distinct intransitive verb construction in this example.) Although Construction Grammar began with the exploration of many unusual constructions (e.g. the "let alone" construction in Fillmore, Kay and O'Connor, 1988), it has come to be recognized that the basic principles of Construction Grammar apply to common constructions as well. In fact, a basic claim of Construction Grammar is that "the network of constructions captures our knowledge of language *in toto* – in other words, it's constructions all the way down" (Goldberg, 2003).

The key insights of Construction Grammar are beginning to have a significant impact on other linguistic formalisms including Cognitive Grammar (Langacker, 1987, 1991; Talmy 2001; Lakoff, 1987), Double R Theory (Ball, 2005)—discussed further below, HPSG (Sag and Wasow, 1999; Sag, 1997) and even Generative Grammar as reformulated by Culicover and Jackendoff (2005).

Constructions

Constructions are learned chunks of linguistic knowledge that tie subordinate linguistic elements together. Fully lexicalized constructions containing multiple words are called *multiword expressions*. Trying to determine the meaning of a multiword expression via composition of the meaning of the individual words it contains will not work since the meaning is not typically fully compositional. Consider the multiword expressions "take a hike", "take a leak", "take five", "take my wife, please!". The meanings of these expressions are not a composition of the meaning of the extremely ambiguous word "take" with the meanings of the other words in the expression. However, multiword expressions are not a "pain in the neck" for language processing as Sag et al. (2002) suggest. Determination of meaning is facilitated by identification of the largest units of meaning (multiword expressions and constructions) in a text or utterance, not by trying to compose meanings from the smallest units of meaning (morphemes and words). Of course, the issues of lexical proliferation and composability that Sag et al. (2002) highlight are still relevant and important for the implementation of a construction based approach to language processing. Further, improved mechanisms for identifying multiword expressions and constructions are needed.

The elements of constructions may be specific lexical items or linguistic categories. The more general a construction, the more likely it is to contain categories rather than lexical items. Categories may be *form-based* or *functional*, although the focus of this paper is on functional categories. (The use of functional categories is motivated in Ball, 2005.) For example, the `[subject predicator object]`$_{clause}$ construction describes a sequence of three functional categories, whereas the `[subject` *`hit`* `object]`$_{clause}$ construction is specific to the verb *`hit`* and the `[subject` *`struck out`*`]`$_{clause}$ construction is specific to the verb-particle combination *`struck out`* (including the past tense marking of *`struck`*). For the most part, constructions are sequence specific, although the possibility of constructions whose elements are not location specific is not precluded.

The following notation is used for the representation of constructions:

$[A_{sub}\ B\ C]_D$

In this representation, square brackets enclose the construction which consists of an ordered list of elements A, B and C. The elements in a construction may be specific lexical items, lexemes (i.e. abstracted dictionary forms) or functional categories (i.e. functionally typed variables). A subscript, $_{sub}$, on an element may be used to indicate a functional subcategory (and conceivably a form-based category). The functional category of the construction is indicated by the subscripted $_D$ to the right of the construction. Lexical items are italicized to distinguish them from lexemes.

Over the course of a lifetime, humans acquire a large knowledge base of constructions at multiple levels of abstraction and generalization. For language comprehension, the most lexically specific constructions matching the input are likely to activated, selected and integrated, and language comprehension can be viewed as lexically driven (within the context of constructions). For example, the `[subject` *`kicked the bucket`*`]`$_{clause}$ construction will be preferred over the `[subject kick object]`$_{clause}$ construction where both are activated by the input, since the former is more lexically specific. In addition, constructions which match the largest chunks of input are likely to be preferred (cf. Grossberg and Myers, 1999). Thus, `[subject` *`ate`* `object]`$_{clause}$ will be preferred over `[subject` *`ate`*`]`$_{clause}$ given the input "she ate the sandwich".

It should be noted that constructions may contain actual and ambiguous lexical items. For example, the construction `[`*`take a hike`*`]`$_{imperative\text{-}clause}$ contains the ambiguous lexical items "take", "a" and "hike". Full representation of the meaning of constructions will require interfacing them to non-linguistic representations of the situations and objects to which they can be used to refer, rather than via disambiguation of the meanings of the lexical items they contain through the use of abstract concepts or word senses. This is an IOU of the current theory which is no worse than the use of uppercase words to inadequately represent meanings and which avoids the fatal limitations of trying to statically predetermine word senses (cf. Kintsch, 2001; Kilgariff, 1997; Dolan, Vanderwende & Richardson, 2000). Research ongoing in our lab on the development of a spatial cognition module for ACT-R (Anderson et al. 2004) and research on Situation Models (Zwann & Radvansky, 1998) and Perceptual Symbol Systems (Barsalou, 1999) are beginning to address the representation of non-linguistic aspects of meaning. A general assumption of this approach is that meanings are primarily associated with referential entities, not individual words as in Kintsch's (2001) examples "the horse ran" vs. "the paint ran" where the meaning of "ran" depends crucially on the object involved in the running.

Construction-Driven Language Processing

A processing mechanism based on the *activation, selection* and *integration* of constructions is proposed. Constructions are activated in memory by an *automatic process* to the extent that they match the current input and prior context. The most highly activated constructions are selected for integration by a *control process*. Selected constructions with categorical elements and as yet unrealized lexical items establish expectations which drive the processing mechanism. Category expectations in constructions can function to establish the category of the prior input or set the context for processing the subsequent input and also determine the how inputs are integrated. For example, the `[subject` *`hit`* `object]`$_{clause}$ construction, activated by the word *`hit`*, establishes the expectations that the prior input is functioning as a `subject` and the subsequent input is functioning as an `object`. A prior input capable of functioning as a subject and a subsequent input capable of functioning as an object can be integrated into this construction. Of course, expectations may be violated and when they are, the violations must be accommodated. Possible mechanisms of *accommodation* include the selection and integration of a different construction (in the context of the expectation violation and not via algorithmic backtracking), modification of the selected construction (Ball, 2004), or construal of the *to be integrated* element as being of the required functional type (Langacker, 2000)—as in construal of "to be integrated" as a nominal head modifier in this sentence. For example, in the context of the construction `[`*`the`* `head]`$_{nominal}$, activated by the processing of *`the`*, the word *`hit`* can be integrated as the `head` and the `[subject` *`hit`* `object]`$_{clause}$ construction may or may not be selected and integrated during processing (although it will probably still be activated). Note that instantiating *`hit`*, a type of action, as the head of a nominal construction involves construing the action that the nominal refers to as though it were an object. This is a common form of construal in English—especially for words describing actions which occur instantaneously and are easily objectified (Ball, 2005).

A construction-driven language processing system is likely to lead to far messier representations than that typically assumed in other computational linguistic or cognitive science approaches. Although constructions can be integrated to some extent, there is no guarantee that this integration will lead to anything like a well-formed tree, let alone a binary branching tree (Kayne, 1994). In fact, to the extent that constructions are independent of each other, they can only be integrated via the lexical items and categories they share. Further, it is likely that constructions will often conflict with each other, leading to representations that are in part inconsistent (in the sense that they assign different or inconsistent representations to the same input). For example, "the thing is, is that constructions may not be fully *integratable*" is an example of the ISIS construction—which is obviously more common in spoken language where there often isn't time to correct for the inconsistent integration of constructions during production (Tuggy, 1996). (The term "integratable" is itself a not entirely consistent mixture of the lexical and morphological constructions [*integrate*]$_{verb}$ and [stem$_{verb}$-*able*]$_{adjective}$ and it is unclear if "integrable" is not more appropriate.) Problems in determining the basic structure of clauses—is it SVO or Subject-Predicate—are a reflection of this inconsistency. The subject has a saliency in the Subject-Predicate construction that is does not have in the more symmetric SVO construction. Both constructions are likely to be available in the inventory of constructions available to fluent comprehenders of English. Which one gets activated and selected (or perhaps both) is likely to vary from utterance to utterance depending on the prior context and variability in the manner and form of expression of the current utterance. For example, in

John hit (pause) and Sue kicked (pause) the door

the Subject-Predicate construction is unlikely to be activated and selected given the conjoining of the subject and verb separately from the object which would normally form part of the predicate (combining with the verb). Similarly, in

He's hitting the ball

the cliticization of is with he argues against activation of a Subject-Predicate construction (assuming the auxiliary verb is normally part of the predicate). In fact, there is very likely to be a specialized [*he's* predication]$_{clause}$ construction that gets activated and selected—where predication is a functional element distinct from the predicate (i.e. the predication lacks the first auxiliary or modal verb). Finally, question forms argue against the necessary activation and selection of a Subject-Predicate construction. Consider

Where is he going?

which suggests a specialized construction like [*where* be subject predication]$_{wh\text{-}clause}$.

In general, there are a number of different constructions which come in to play in the processing of clausal heads. These constructions overlap in various respects, but all of them can be empirically motivated.

(he's) kicking the ball →
[V$_{head}$ obj$_{comp}$]$_{predication}$
(he) is kicking and was hitting (the ball) →
[be$_{spec}$ V-ing$_{head}$]$_{predicator}$
(he) kicked the ball →
[V-ed$_{spec/head}$ obj$_{comp}$]$_{predicate}$
(why did) he kick the ball →
[subj$_{comp}$ kick$_{head}$ obj$_{comp}$]$_{proposition}$

The term *predication* is used to describe a construction consisting of an untensed clausal head along with non-subject complements. The term *predicator* is used to describe a construction consisting of a clausal head along with its tense specification. Note that the head of a predication or predicator need not be a verb, nor is an object required in a predication. In "he is *running*", the verb "running" is the head, in "he is *sad*", the adjective "sad" is the head, and in "he is *there*", the adverb "there" is the head –and there is no object in these examples. The functional categories predicator and predication generalize over these alternative phrasal forms (Ball, 2005). The term *predicate* is used to describe a construction consisting of a clausal head along with its tense specification and non-subject complements. The term *proposition* is used to describe a construction consisting of an untensed clausal head along with its complements (including the subject).

A Processing Example

During the processing of the sentence

He is kicking the ball

the following constructions are likely to be activated:

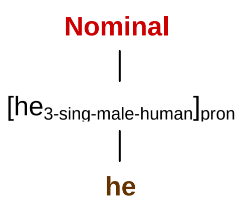
he → [*he*$_{3\text{-}sing\text{-}male\text{-}human\text{-}pron}$]$_{nominal}$
is → [be$_{3\text{-}pres\text{-}sing}$]$_{verb}$
he is → [ref-pt$_{comp}$ be$_{spec}$ predn$_{head}$]$_{clause}$
kicking → [kick$_{v\text{-}ing}$]$_{verb}$
kicking →
[subj$_{comp}$ kick$_{head}$ obj$_{comp}$]$_{proposition}$
kicking → [V$_{head}$ obj$_{comp}$]$_{predication}$
is kicking → [be$_{spec}$ V-ing$_{head}$]$_{predicator}$
the → [the$_{spec}$ head]$_{nominal}$
the ball → [the$_{spec}$ ball$_{head}$]$_{nominal}$

The [*he*$_{3\text{-}sing\text{-}male\text{-}human\text{-}pron}$]$_{nominal}$ construction encodes the knowledge that pronouns like "he" (3rd person, singular, male, human) can function as full nominals, encoding both a *referential specifier* function and an *objective head* function (Ball, 2005). The [be$_{3\text{-}pres\text{-}sing}$]$_{verb}$ construction encodes the status of "is" as the 3rd person, present tense, singular form of the verb "be". The [ref-pt$_{comp}$ be$_{spec}$ predn$_{head}$]$_{clause}$ construction captures the use of a *reference point* complement (Taylor, 2000) and a referential specifier (be$_{spec}$) to tie a predication functioning as head of a clause to the larger discourse situation via the reference point and referential specifier. This construction is related to the basic *subject-predicate* form of a clause with be$_{spec}$ and predn$_{head}$ together constituting the *predicate* (which is not a distinct constituent in this construction) and predn$_{head}$ alone constituting a *predication*. In the case of a tensed verb without a separate auxiliary (e.g. "kicked"), the construction has the form [ref-pt$_{comp}$ pred$_{head}$]$_{clause}$ where pred$_{head}$ constitutes a *predicate* (and distinct constituent) which encodes the tensed verb and post-head complements and ref-pt$_{comp}$ corresponds to the *subject*. The [kick$_{v\text{-}ing}$]$_{verb}$ construction captures the "V-ing" (i.e. progressive) verb form of "kicking". The [subj$_{comp}$

kick$_{head}$ obj$_{comp}$]$_{proposition}$ construction captures the basic relational meaning of the verb “kick” which combines with a subject and object complement to form a *proposition*. This construction is closely related to the basic SVO form of a clause. The [V$_{head}$ obj$_{comp}$]$_{predication}$ construction captures the combining of a tenseless verb head with an object complement to form a *predication* that functions as the head of the [ref-pt$_{comp}$ be$_{spec}$ predn$_{head}$]$_{clause}$ construction. The [be$_{spec}$ V-ing$_{head}$]$_{predicator}$ construction captures the combining of the auxiliary verb “be” functioning as a specifier with the progressive form of a verb functioning as the head in forming a *predicator*. The [the$_{spec}$ head]$_{nominal}$ construction captures the encoding of a referential specifier and objective head to form a nominal. The [the$_{spec}$ ball$_{head}$]$_{nominal}$ construction captures the encoding of “ball” as the head of the [the$_{spec}$ head]$_{nominal}$ construction.

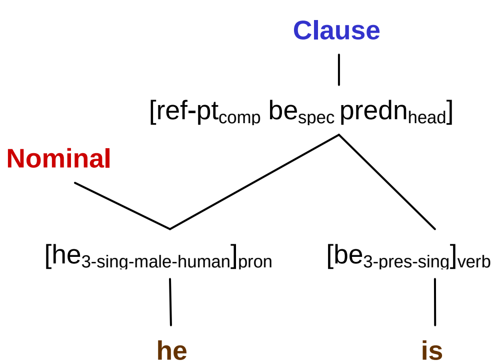
The actual processing of this utterance is likely to proceed as follows:

he →



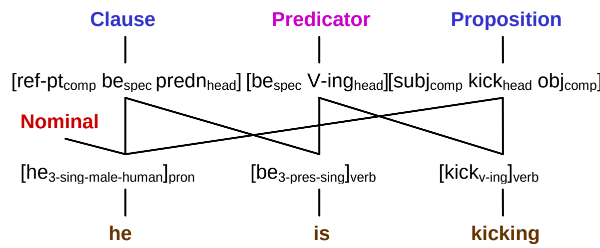
The word “he” activates a *nominal* construction which is capable of referring to some object independently of any larger linguistic unit in which it may participate.

he is →



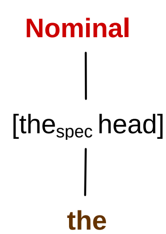
The word “is” following “he” activates a *clause* construction. The assumption here is that the subject nominal “he” and auxiliary verb “is” are immediately integrated into the [ref-pt$_{comp}$ be$_{spec}$ predn$_{head}$]$_{clause}$ construction. In general, delaying integration of linguistic elements into constructions is likely to lead to processing problems since the need to retain separate linguistic units in memory will run up against limits on the number of unchunked linguistic elements which can be separately retained in *working memory*.

he is kicking →



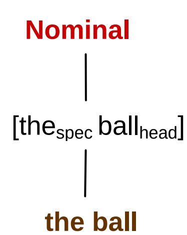
Two additional constructions—*predicator* and *proposition*—are activated by “kicking” and immediately integrated to the extent possible. It is assumed that the *predicate* construction is not activated by this input since the word “is” which bears the tense is separate from the main verb “kicking”.

the →

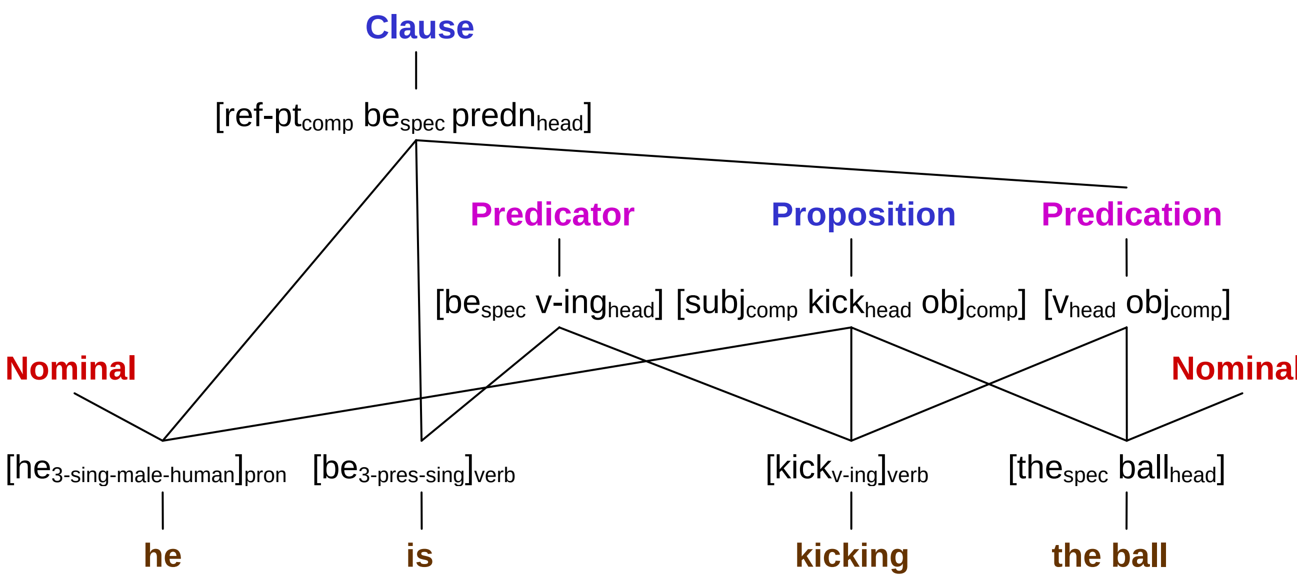


The word “the” activates a *nominal* construction that is not integrated into the preceding representation until the head of the construction is instantiated. This is an exception to the general rule that linguistic elements are immediately integrated into constructions. This exception is motivated by the assumption that once an element is integrated into a construction, it is less readily available during subsequent processing for instantiation of sub-elements.

the ball →



The noun “ball” is integrated as the head of the nominal “the ball” and the full nominal can now be integrated into the preceding representation leading to the following linguistic representation for the utterance “he is kicking the ball”:



This representation is considerably more complex than that typical of many computational linguistic and cognitive science theories (although perhaps no more complex than many proposed representations within generative linguistic theory). The representation can be simplified if not all the activated constructions are selected and integrated. However, all the constructions are candidates for integration, whether or not they are actually selected for integration. The representation is clearly not a well-formed tree, but a collection of trees with shared leaves in the lexical items that activated the constructions.

One way of viewing such representations is as having multiple tiers corresponding to different dimensions of meaning encoded via constructions. Constructions which capture referential meaning ($[\texttt{ref-pt}_{comp}\ \texttt{be}_{spec}\ \texttt{predn}_{head}]_{clause}$) constitute a tier that is distinct from constructions which capture relational meaning ($[\texttt{subj}_{comp}\ \texttt{kick}_{head}\ \texttt{obj}_{comp}]_{proposition}$). These different tiers of meaning get integrated just to the extent that they have overlapping lexical items and functional categories. Such an approach opens up the possibility of having additional tiers to capture meaning distinctions conveyed by topic-focus and given-new contrasts, among others.

Relationship to Double R Theory

Ball (2005) presents a bi-polar theory of nominal and clause structure and function—Double R Theory—that provides much of the linguistic theory underlying the processing mechanism put forward in this paper. However, the focus of Double R Theory is on the joint encoding of referential and relational meaning and it is generally assumed that a fully integrated representation is possible. In considering the use of constructions as the basis for language processing and representation, it becomes clear that a fully integrated representation may not in principle be possible. Instead, the representations are likely to be integrated just to the extent supported by the overlapping elements of the constructions activated by the input and selected for integration. Tensions resulting from the difficulties of jointly encoding referential and relational meaning are acknowledged in Double R Theory, but in extending Double R Theory to constructions, it becomes clear that competing representations need not be fully integratable. In fact, a tiered approach to representing different dimensions of meaning much like that put forward in current theories of phonology (cf. Kaye, 1989) may be more appropriate.

Double R Theory has been partially implemented as a cognitive model of language comprehension—Double R Model—using the ACT-R cognitive architecture and modeling environment (Anderson & Lebiere, 1998; Anderson et al. 2004). An initial application area of Double R Model involves the processing of Pilot Comm—a specialized sublanguage used for communication between pilots and air operations personnel (e.g. AWACS radar operators) in the US Air Force. Pilot Comm is constrained by the need for brevity, the potential for crosstalk, and the prevalence of noise on the communications channel and in the cockpit. At least in part due to brevity concerns, pilot comm dispenses with many of the referential and relational cues which occur in normal language. These cues are replaced by learned constructions which provide the context for understanding pilot comm utterances. For example, the following pilot comm utterance is uninterpretable without reference to the specialized constructions which give it meaning:

Eagle 1, Darkstar, one group bullseye 230 12 12000

In particular, there is a specialized *communication* construction of the form

$[\texttt{hearer}_{call\text{-}sign}\ \texttt{speaker}_{call\text{-}sign}\ \texttt{message}]_{comm}$

there is a *bullseye* construction of the form

$[\texttt{object}\ \textit{bullseye}\ \texttt{BRAA}]_{message}$

and there is a *BRAA* construction of the form

`[bearing range altitude (aspect)]`$_{BRAA}$

which provide the context for interpreting this pilot comm utterance. The *communication* construction explicitly includes expression of the call signs of the speaker and hearer as a mechanism for dealing with crosstalk in the conveying of a message to the intended recipient. The *bullseye* construction supports identification of an object—typically an aircraft or group of aircraft—and specification of the object's location with respect to a predetermined reference point or landmark called the "bullseye" (bearing relative to bullseye in degrees—230, range or distance relative to bullseye in miles—12, and altitude in feet—12000) and the direction (aspect) of the object relative to the hearer via the embedded *BRAA* construction. The BRAA construction has parentheses around the `aspect` element to indicate the optionality of this element. If not specified (as in this example), the `aspect` defaults to `HOT` (coming towards the hearer). More specific BRAA constructions may be needed to fully capture this distinction.

It is the availability of these specialized constructions which obviates the need for the more general referential and relational cues typically used in less specialized language. The addition of these specialized constructions extends the coverage of Double R Theory to the Pilot Comm domain and suggests that the referential and relational schemas of Double R Theory are general constructions which only take precedence in the absence of more specialized constructions. Of course, this was always an assumption of Double R Theory, but its application to Pilot Comm makes this explicit.

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