A sensorimotor characterisation of syntax, and its implications for models of language evolution

Alistair Knott

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What’s the best piece of news you can imagine receiving as a language evolution researcher?

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Fodor’s idea: language and the SM system are modules.
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An alternative idea: language and the SM system share machinery.
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An alternative idea: language and the SM system share machinery. Some language circuits just ‘read out’ SM representations.
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An alternative idea: language and the SM system share machinery. Part of the syntactic structure of language is sensorimotor in origin.
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Why would this be good news for language evolution researchers?
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(1) It makes it very likely that some linguistic mechanisms evolved as biological adaptations of the SM system.
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(2) We can use the modern SM system to approximate the platform from which language evolved.
Aim of the talk

I’ll propose that for \textit{simple, concrete} sentences, syntactic structure really is largely sensorimotor in origin.
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I’ll argue for a particularly strong hypothesis:

The syntactic structure of a simple sentence reporting a concrete episode in the world can be understood as a description of the sensorimotor processes involved in apprehending that episode.
I’ll propose that for *simple*, *concrete* sentences, syntactic structure really is largely sensorimotor in origin.

I’ll argue for a particularly strong hypothesis:

*The syntactic structure of a simple sentence reporting a concrete episode in the world can be understood as a description of the sensorimotor processes involved in apprehending that episode.*

This would be particularly good news for language evolution researchers.
An objection

‘Languages of the world are very different from one another, but we all have the same sensorimotor processes.’

To maintain the strong hypothesis, we must adopt a syntactic theory in which differences between sentences reporting the same episode in different languages are relatively superficial.
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‘Languages of the world are very different from one another, but we all have the same sensorimotor processes.’

To maintain the strong hypothesis, we must adopt a syntactic theory in which differences between sentences reporting the same episode in different languages are relatively superficial.

Perhaps surprisingly, the syntactic framework we are drawn towards is some form of Chomskyan generative grammar.

- Sentences have a ‘surface’ structure and an ‘underlying’ structure.
- It’s the *underlying* structure which can be interpreted as a description of SM processing.
Method

Take a simple example episode: \textit{a man grabs a cup}.

Develop two models:

- A \textbf{syntactic model} of the (underlying) structure of sentences reporting this episode in different languages, according to some variety of Chomskyan syntax.

- A \textbf{sensorimotor model} of the processes which allow the episode to be perceived or executed, according to current psychology/neuroscience.

Question: do these models overlap?

I argue that there are formal similarities between the syntactic and sensorimotor models, which are strong enough to require explanation.
I assume a version of Minimalism (Chomsky, 1995).

In Minimalism, a sentence needs to be described at two different syntactic levels:

- **Phonetic form (PF)** represents the surface form of the sentence.
- **Logical form (LF)** is ‘the level of syntactic representation which interfaces with the semantic system’.

I’ll assume that all translations of *The man grabbed a cup* have the same LF.
The building blocks of syntactic structures

The basic unit of phrase structure is the X-bar schema.

```
XP
 / \  
Spec X'
 /   
X    Comp
```

Each word in a sentence contributes an XP structure.

- The **head** of the structure (X) is the word itself.
- The structure also has slots for a **specifier** (Spec) and a **complement** (Comp).
- These slots can (recursively) be occupied by other XPs.
The LF of our sentence is a right-branching pattern of XPs.
LF structure of *The man grabbed a cup*

IP is associated with the subject.
A syntactic model of *The man grabbed a cup*

**LF structure of The man grabbed a cup**

AgrP is associated with the object.
A syntactic model of *The man grabbed a cup*

**LF structure of *The man grabbed a cup***

AgrP is associated with the verb.
LF structure of *The man grabbed a cup*

VP is headed by the verb, and introduces the subject and object.
The subject raises to [Spec,IP] to get Case (assigned by I)
A syntactic model of *The man grabbed a cup*

**LF structure of *The man grabbed a cup***

The object raises to [Spec, AgrP] to get **Case** (assigned by Agr)

![Diagram of LF structure]
The verb raises successively to Agr and I.

LF structure of *The man grabbed a cup*

```
IP
  Spec the man
  I
  AgrP
    Spec a cup
    Agr
      VP
        Spec
        V
          V grabbed
          DP
```
The verb raises successively to Agr and I.
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LF structure of *The man grabbed a cup*

The verb raises successively to Agr and I.
Languages have different conventions about when to pronounce the different elements of LF.

LF structure of *The man grabbed a cup*

\[\text{Spec} \quad \text{I'} \quad \text{Spec} \quad \text{Spec} \quad \text{V'} \quad \text{V'} \quad \text{Spec} \quad \text{Spec} \quad \text{DP} \quad \text{Agr} \quad \text{Agr} \quad \text{Agr} \quad \text{Agr} \quad \text{I} \quad \text{IP} \]

\[
\begin{array}{c}
\text{the man} \\
\text{grabbed} \\
\text{a cup} \\
\text{the man} \\
\text{grabbed} \\
\end{array}
\]
LF structure of *The man grabbed a cup*

English PF looks like this:
Māori PF looks like this:
LF structure of *The man grabbed a cup*

Japanese PF looks like this:

```
IP
   /\   _    _       _    _
  I' _/ \ _/  \ _/  \ _/  \_/
      II   _/  \_/  \_/  \_/
     Spec the man

AgrP
   _/  \_/  \_/
   I

Spec a cup
   _/  \_/
   Agr

VP
   _/  \_/
   Spec

V
 V'    _/
     V grabbed

DP
```
1. I argue that the processes involved in perceiving or executing a reach-to-grasp action have a strong *sequential structure*:

- The observer must first attend to the agent
- and then attend to the target
- and only then dynamically monitor the action to completion.
Some evidence from an eye-tracking study

(Webb et al. ‘Eye movements during transitive action observation have sequential structure’, Acta Psychologica 2010)
2. I argue that both agent and target are reattended to when the action is experienced.

- During action monitoring, the agent is reattended to as a dynamic entity.
- At the end of the action, the target is reattended to as a motor state.

I suggest that these actions of reattention are crucial for the development of cross-modal object representations.
## SM signals during experience of a reach-to-grasp

<table>
<thead>
<tr>
<th>Context</th>
<th>Action signals</th>
<th>Reafferent signals</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td><code>attend_agent</code></td>
<td><code>attending_to_agent</code></td>
</tr>
<tr>
<td>C2</td>
<td><code>attend_cup</code></td>
<td><code>attending_to_cup</code></td>
</tr>
<tr>
<td>C3</td>
<td><code>grasp</code></td>
<td><code>attending_to_agent</code></td>
</tr>
<tr>
<td>C4</td>
<td></td>
<td><code>attending_to_cup</code></td>
</tr>
</tbody>
</table>
My proposal (roughly):

_The LF of ‘The man grabbed a cup’ describes the sequence of SM operations/states evoked during experience of a cup-grabbing event._
I express this proposal by giving a general SM interpretation of an XP schema.

> XP
>   [Spec,XP] X’
>     X YP

- SM characterisation of syntax
- SM characterisation of LF
I express this proposal by giving a general SM interpretation of an XP schema.

- An XP in an LF structure denotes a SM operation, executed in a certain initial context, which generates a reafferent consequence, and establishes a new context.
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- An XP in an LF structure denotes a *SM operation*, executed in a certain *initial context*, which generates a *reafferent consequence*, and establishes a *new context*.
- Each item in the XP schema has a SM interpretation.
XPs denoting attentional operations

IP and AgrP denote attentional operations, and their reafferent consequences.

In these XPs:
- The head (which ‘checks’ a piece of verb morphology) denotes an action of attention.
- The specifier (the position occupied by a DP) denotes the sensory representation of an object.
XPs denoting motor operations

VP denotes a motor operation, and its reafferent consequences.

The V head denotes a motor programme.

The specifier of VP denotes the sensory representation of an agent.
A right-branching structure of X-bar schemas

In a right-branching X-bar structure, the next context of one XP is the initial context of its complement XP.

So a right-branching structure of XPs describes a sequence of sensorimotor operations.
SM interpretation of the LF of *The man grabbed a cup*

The four LF projections map onto the four stages of the SM sequence.
The four LF projections map onto the four stages of the SM sequence.

The sentence “The man grabbed a cup” is analyzed with the following LF representation:

- **Spec IP**: the man
- **I’**: grabbed
- **AgrP**: a cup
- **Spec Agr’**: a cup
- **V’**: grabbed
- **Spec V**: the man
- **VP**: grabbed
- **Agr**: a cup
- **DP**: a cup

This diagram illustrates the syntactic structure of the sentence, showing how the various LF projections correspond to the different stages of the SM sequence.
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The diagram illustrates the syntactic structure of the sentence, showing the roles of the main constituents and their relationships. The labels such as `attending_agent`, `attend_to_agent`, `attending_cup`, `attend_to_cup`, `Spec`, `Agr`, `Spec`, `Agr`, `V`, and `DP` represent the different syntactic roles and positions within the sentence.
SM interpretation of the LF of *The man grabbed a cup*

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![Diagram](chart.png)
The four LF projections map onto the four stages of the SM sequence.

The diagram illustrates the syntactic structure and the corresponding LF projections. Each projection corresponds to a specific stage of the SM sequence, with nodes representing syntactic categories and edges showing the dependencies between them.
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attending_agent
  Spec
  the man

attend_to_agent
  I
  grabbed

attending_cup
  Spec
  a cup

attend_to_cup
  Agr
  grabbed

attending_agent
  Spec
  the man
  V
  grabbed
  DP
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```

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SM interpretation of the LF of *The man grabbed a cup*

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So: what’s the SM characterisation of movement?
SM interpretation of the LF of *The man grabbed a cup*

DP raising reflects operations of *re-attention to agent and patient*.
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SM interpretation of ‘DPs must raise to check Case’: Objects must be attended to before being involved in action monitoring.
There’s a neat SM interpretation of V-Agr-I raising too.
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E.g. there’s a natural model of sentence generation:

- An agent generating a (concrete) sentence internally rehearses a SM sequence stored in working memory, producing words as behavioural side-effects.
Interpreting LF as describing a SM sequence allows us to think of Minimalism as a processing model, as well as just a model of ‘syntactic competence’.

E.g. there’s a natural model of sentence generation:
- An agent generating a (concrete) sentence internally rehearses a SM sequence stored in working memory, producing words as behavioural side-effects.

And of syntactic development:
- The agent learns which SM signals to ‘read out’ as words, and which to suppress.
I have developed a neural network model of this generation/learning mechanism, which can handle idioms as well as productive syntactic constructions. (Joint work with Martin Takac and Lubica Benuskova.)

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Language processing and syntactic development

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The model should look familiar to connectionist linguists. But it can also be interpreted by Minimalist linguists as a model of how speakers learn to set ‘UG parameters’ governing word order.
Beyond grabbing cups

I’ve just finished a book, called *Sensorimotor cognition and natural language syntax*, which goes into detail about all the models just described. (See my publications webpage.)
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The book also extends the SM interpretation of LF to several other constructions:

- The internal structure of noun phrases
- Predicative clauses
- Quantification
- Relative clauses.
Implications for an account of language evolution

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Basic proposal: a lot of the syntax of concrete sentences is actually sensorimotor in origin.
Implications for language evolution

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A possible timeline for language evolution:
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A possible timeline for language evolution:

- Early hominins have a fairly modern SM system, including a mechanism for storing and replaying SM sequences.
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- Early hominins have a fairly modern SM system, including a mechanism for storing and replaying SM sequences.
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- A circuit evolves for mapping static SM signals to overt behaviours, allowing the production of simple word sequences.
- A new circuit evolves, co-opting the simple language circuit and the SM sequence rehearsal mechanism, which generates word sequences *from SM sequences*. 