Syntactic structures as traces of sensorimotor event representations

Alistair Knott
Dept of Computer Science
University of Otago
Two approaches to the study of actions

A simple example event: a man grabs a cup.

This event can be studied from two points of view:

• Linguists are interested in analysing sentences which describe the event (e.g. The man grabbed a cup).
• Psychologists are interested in understanding how the event can be recognised, performed, remembered etc.
The language/sensorimotor interface

Clearly we can convert sensorimotor representations into linguistic ones (and vice versa).

- Because we can talk about what we see;
- Because we can execute verbal instructions.

Question: how much work is involved in this conversion?
Two suggestions

Language and SM processing are **modules**

Language processing mechanisms

Sensorimotor processing mechanisms

Language processing mechanisms share mechanisms

Sensorimotor processing mechanisms
Methodology

I’m interested in exploring the second suggestion. My approach is to look for formal similarities between models of sensorimotor cognition and models of sentence syntax.

• If there are nontrivial similarities, then maybe linguists and SM psychologists are actually studying the same thing without realising it.
Outline of the talk

1. A sensorimotor model of transitive actions
2. A syntactic model of transitive actions
3. A suggestion: the syntactic model can be understood as a description of operations in the sensorimotor model.
Preliminaries for the sensorimotor model

A model of ‘proposition-sized’ cognitive phenomena must draw on work in several different areas of psychology: vision, attention, motor control, working memory, episodic memory.

The model which follows is a synthesis of models from these different areas.
Visual ‘what’ and ‘where’ pathways
The reach and grasp pathways
The modulatory role of PFC
The action recognition pathway
The ‘who’ pathway

- Retina
- Visual cortex: V1, V2, V3, V3a, V4, MT, MST
- Inferotemporal cortex: TEO, TE
- LIP, FEF
- Prefrontal cortex: PFC
- Premotor cortex: F4, F7, F2, F5 canonical
- Motor cortex: F1
- Parietal cortex: VIP, V5, V6a, PEA, MIP, C–IPS, AIP
- STS
- F5 mirror: PF/PFG

Arrow labels:
- "change task"
- 'attend to self'
- 'attend to other'
‘Action execution mode’

- **retina**
  - **visual cortex**: V1, V2, V3, V3a, V4, MT, MST
  - **parietal cortex**: VIP, V5, V6a, PEA, MIP, C–IPS, AIP
  - **inferotemporal cortex**: TEO, TE
- **prefrontal cortex (PFC)**
- **premotor cortex**: F4, F7, F2, F5 canonical
- **motor cortex**: F1
- **STS**
- **F5 mirror**: PF/PFG

Keywords: change task, attend to self
‘Action recognition mode’

- retina
- visual cortex V1 V2 V3 V3a V4 MT MST
- parietal cortex VIP V5 V6a PEa MIP C−IPS AIP
- inferotemporal cortex TEO TE
- premotor cortex F4 F7 F2 F5 canonical
- motor cortex F1
- STS
- F5 mirror PF/PFG
- ‘attend to other’
- ‘change task’
- prefrontal cortex PFC
- LIP FEF

---

14
Some references

• IT cortex: object classification (e.g. Logothetis, 1998)
• FEF: saliency map (e.g. Thomson et al, 2001)
• Parietal cortex: coordinate system transformations (e.g. Andersen et al., 1997; Burnod et al. 1999)
• F4: arm goal position (e.g. Luppino and Rizzolatti, 2000)
• F5: hand motor programmes (e.g. Rizzolatti et al., 1988)
• PFC: Miller and Cohen (2001); Braver and Cohen (2000)
Some references

- Superior temporal sulcus for biological motion recognition (e.g. Oram and Perrett, 1994)
- Mirror neurons in PF/PFG (e.g. Gallese et al., 2002)
- Hebbian models of ‘deep’ action recognition (e.g. Iacoboni et al., 2001; Fogassi et al., 2005; Keysers and Perrett, 2004)
- ‘Mode-setting’ model of self vs other (Farrer and Frith, 2002)
How is processing organised in the network as a whole?

- NB: most representations in the network are *transitory*.
- So it will move through a *sequence* of states.
Deictic routines

A deictic representation is a transitory representation linked to the current focus of attention (Ballard et al., 1995).

The current deictic representation can determine how attention is shifted to the next object.

This cycle allows the development of deictic routines, involving sequences of directions of attention.
Deictic routines

A deictic representation is a transitory representation linked to the current focus of attention (Ballard et al., 1995).

The current deictic representation can determine how attention is shifted to the next object.

A proposal: ‘events’ such as transitive actions are structured as deictic routines.
Proposal about transitive action execution

Stage 1: the observer is in an attentional state where objects in the world compete for his attention.

Stage 2: the observer attends to himself, configuring his mirror system circuit for action execution.

Stage 3: the observer creates a new attentional environment, centred on his own body, biased to objects within reach.

Stage 4: the observer executes an action of attention and ends up attending to (and categorising) a cup.
Proposal about transitive action execution

**Stage 1:** the observer is in an attentional state where objects in the world compete for his attention.

**Stage 2:** the observer attends to himself, configuring his mirror system circuit for action execution.

**Stage 3:** the observer creates a new attentional environment, centred on his own body, biased to objects within reach.

**Stage 4:** the observer executes an action of attention and ends up attending to (and categorising) a cup.
Proposal about transitive action execution

**Stage 1:** the observer is in an attentional state where objects in the world compete for his attention.

**Stage 2:** the observer attends to himself, configuring his mirror system circuit for action execution.

**Stage 3:** the observer creates a new attentional environment, centred on his own body, biased to objects within reach.

**Stage 4:** the observer executes an action of attention and ends up attending to (and categorising) a cup.
Proposal about transitive action execution

**Stage 1**: the observer is in an attentional state where objects in the world compete for his attention.

**Stage 2**: the observer attends to himself, configuring his mirror system circuit for action execution.

**Stage 3**: the observer creates a new attentional environment, centred on his own body, biased to objects within reach.

**Stage 4**: the observer executes an action of attention and ends up attending to (and categorising) a cup.
Proposal about transitive action execution

Stage 5: the observer creates a new attentional environment, in which several possible alternative actions (on the cup) are represented, and compete amongst one another.

Stage 6: the observer selects one of these actions (‘grab’). This triggers physical motion. As a side-effect of this motion, the observer again attends to himself.

Stage 7: when the action is completed, the agent again attends to the cup, this time in the haptic modality.
Proposal about transitive action execution

Stage 5: the observer creates a new attentional environment, in which several possible alternative actions (on the cup) are represented, and compete amongst one another.

Stage 6: the observer selects one of these actions (‘grab’). This triggers physical motion. As a side-effect of this motion, the observer again attends to himself.

Stage 7: when the action is completed, the agent again attends to the cup, this time in the haptic modality.
Proposal about transitive action execution

Stage 5: the observer creates a new attentional environment, in which several possible alternative actions (on the cup) are represented, and compete amongst one another.

Stage 6: the observer selects one of these actions (‘grab’). This triggers physical motion. As a side-effect of this motion, the observer again attends to himself.

Stage 7: when the action is completed, the agent again attends to the cup, this time in the haptic modality.
Proposal about trans. action recognition

Stage 1: the observer is in an attentional state where objects in the world compete for his attention.

Stage 2: the observer attends to a third party, establishing the ‘action recognition’ mirror circuit.

Stage 3: the observer creates a new attentional environment, centred on the agent and biased towards objects in his peripersonal space.

Stage 4: before the agent’s action is complete, the observer saccades to the target and categorises it.
Proposal about trans. action recognition

Stage 1: the observer is in an attentional state where objects in the world compete for his attention.

Stage 2: the observer attends to a third party, establishing the ‘action recognition’ mirror circuit.

Stage 3: the observer creates a new attentional environment, centred on the agent and biased towards objects in his peripersonal space.

Stage 4: before the agent’s action is complete, the observer saccades to the target and categorises it.
Proposal about trans. action recognition

Stage 1: the observer is in an attentional state where objects in the world compete for his attention.

Stage 2: the observer attends to a third party, establishing the ‘action recognition’ mirror circuit.

Stage 3: the observer creates a new attentional environment, centred on the agent and biased towards objects in his peripersonal space.

Stage 4: before the agent’s action is complete, the observer saccades to the target and categorises it.
Proposal about trans. action recognition

Stage 1: the observer is in an attentional state where objects in the world compete for his attention.

Stage 2: the observer attends to a third party, establishing the ‘action recognition’ mirror circuit.

Stage 3: the observer creates a new attentional environment, centred on the agent and biased towards objects in his peripersonal space.

Stage 4: before the agent’s action is complete, the observer saccades to the target and categorises it.
Proposal about trans. action recognition

**Stage 5:** the observer creates a new attentional environment, in which several possible alternative actions on the cup compete amongst one another.

**Stage 6:** the observer’s biological motion recognition system is engaged, and the correct action (‘grab’) is identified. As a side-effect, the observer attends back to the agent.

**Stage 7:** when the action is completed, the observer again attends to the cup.
Proposal about trans. action recognition

**Stage 5**: the observer creates a new attentional environment, in which several possible alternative actions on the cup compete amongst one another.

**Stage 6**: the observer’s biological motion recognition system is engaged, and the correct action (‘grab’) is identified. As a side-effect, the observer attends back to the agent.

**Stage 7**: when the action is completed, the observer again attends to the cup.
Proposal about trans. action recognition

**Stage 5**: the observer creates a new attentional environment, in which several possible alternative actions on the cup compete amongst one another.

**Stage 6**: the observer’s biological motion recognition system is engaged, and the correct action (‘grab’) is identified. As a side-effect, the observer attends back to the agent.

**Stage 7**: when the action is completed, the observer again attends to the cup.
## Support for the model

<table>
<thead>
<tr>
<th>Statement</th>
<th>Relation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attention is needed for object categorisation (Treisman and Gelade, 1980 &amp;ff)</td>
<td>S1 &lt; S2</td>
</tr>
<tr>
<td></td>
<td>S3 &lt; S4</td>
</tr>
<tr>
<td>Attention can use a body-centred reference frame (Bisiach, 1986; Andersen, 2000)</td>
<td>S3</td>
</tr>
<tr>
<td>Info about the agent’s posture is needed to create a body-centred reference frame</td>
<td>S2 &lt; S3</td>
</tr>
<tr>
<td>Only attended-to targets elicit F5 grasp responses (Rizzolatti et al)</td>
<td>S4 &lt; S5</td>
</tr>
<tr>
<td>Attention can use an action-centred frame of reference (Tipper et al, 1998)</td>
<td>S5</td>
</tr>
</tbody>
</table>
### Support for the model

<table>
<thead>
<tr>
<th>Statement</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Object categorisation occurs during biological motion processing (Giese, 2000)</td>
<td>S6</td>
</tr>
<tr>
<td>Biological motion processing requires attention (Cavanagh et al., 2001)</td>
<td>S4 &lt; S6</td>
</tr>
<tr>
<td>An object must be attended to before it can be reached for (Jeannerod, 1996)</td>
<td>S4 &lt; S6</td>
</tr>
<tr>
<td>The target of an observed action is anticipated by the observer (Flanagan, 2003)</td>
<td>S4 &lt; S5/6</td>
</tr>
</tbody>
</table>
A sequence-based semantics for actions

Summary: a transitive action is perceived as a sequence, in which the agent, patient and action occupy characteristic serial positions.

A suggestion: transitive actions are not only perceived as sequences, but stored in working memory as such.

- WM can hold *planned* actions (i.e. planned sequences)
- WM can hold *observed actions* (i.e. stored sequences)
PFC and working memory

PFC is held to be the locus of many ‘working memory’ functions.

So, we might imagine that:

- Prior to executing a reach action, the agent activates a PFC representation encoding a planned sequence.
- When observing a reach action, the observer *ends up* activating a PFC representation encoding this same plan.

Q: What might this PFC representation look like?
In Miller and Cohen’s model, PFC biases neurons in the stimulus-response pathway, influencing competition between them, and selecting particular S-R pathways.
A model of sequence representation in PFC

If reafferent sensory consequences of earlier actions count as new sensory stimuli, PFC can represent planned sequences of actions.
A model of sequence representation in PFC

The PFC representation is tonically active before, during and after sequence execution. So it can also operate in action observation, to hold the agent’s inferred intention.
A model of sequence representation in PFC

The PFC representation is tonically active before, during and after sequence execution. So it can also operate in action observation, to hold the agent’s inferred intention.
A model of sequence representation in PFC

This PFC representation could also support *replaying* of executed or perceived sequences to longer-term memory stores (c.f. Baddeley’s ‘episodic buffer’).
A role for ‘context’ representations

It’s probably unrealistic to assume that the ‘input’ to the S-R pathway is always a single stimulus.

I assume that stimuli have their influence indirectly, by updating a representation of ‘the current context’.

- Current context is computed from the most recent stimulus, and also from its previous state.
- Context could be stored in another PFC area (see e.g. Beiser and Houk’s model of sequence encoding).
A role for ‘context’ representations

S1
S2
R1
R2

context
parietal/premotor network

sensory stimuli

PFC

responses
Sensorimotor model: summary

So: what’s the SM representation of a transitive action?

Suggestion: it’s an active representation, consisting of the ‘playing’ of a SM sequence stored in working memory.

- There’s a tonic component: the PFC sequence plan
- There’s a phasic component: a sequence of SM states and contexts.
SM sequence for *The man grabbed the cup*
SM sequence for *The man grabbed the cup*
SM sequence for *The man grabbed the cup*

The diagram represents the sequence of events involved in the sentence. The sequence starts with attending to the man, then to the cup, and finally grabbing the cup. The transition from one event to the next is indicated by the arrows connecting the nodes. The initial node C0 represents the start of the sequence.
SM sequence for *The man grabbed the cup*

```
attend-man-then-
attend-cup-then-grab
```

- man
- cup
- grab

'Send'
SM sequence for *The man grabbed the cup*

![Diagram showing SM sequence for "The man grabbed the cup"]
SM sequence for *The man grabbed the cup*

```
SM sequence: attend−man−then−attend−cup−then−grab

Nodes:
- C1
- man
- cup
- grab

Edges:
- attend−man
- attend−cup
- grab
- 'end'
```
SM sequence for *The man grabbed the cup*

![Diagram of SM sequence](image)
SM sequence for *The man grabbed the cup*

```
man
|
C2
|
|
cup
|
|
grab
```

- `attend-man`
- `attend-cup`
- `grab`
- `’end’`
SM sequence for *The man grabbed the cup*
SM sequence for *The man grabbed the cup*
SM sequence for The man grabbed the cup

C3

attend-man
attend-cup
grab
’end’
SM sequence for "The man grabbed the cup"
SM sequence for *The man grabbed the cup*

- attend→man→then→
  - attend→cup→then→grab
- attend→man
- attend→cup
- grab
- ’end’
A model of sentence syntax
A model of sentence syntax

The syntactic framework I’m using is Minimalism (Chomsky, 1995). Very briefly:

- Sentences have a **phonetic form** (PF) and an underlying **logical form** (LF).
A model of sentence syntax

The syntactic framework I’m using is Minimalism (Chomsky, 1995). Very briefly:

- Sentences have a **phonetic form (PF)** and an underlying **logical form (LF)**.
- The building block for LF and PF is the **X-bar schema**.
The structure of a transitive clause
The structure of a transitive clause
DP movement

In Minimalism, subject and object DPs need two things:

- a thematic role (e.g. AGENT or PATIENT)
- Case (e.g. NOM or ACC).

They get their thematic role within the VP.

They need to move to higher Spec positions to get Case. (They’re assigned Case by I and Agr.)
**V movement**

The verb originates at V.
Its *inflections* originate at Agr and I.

- **In finite sentences**, V is inflected:
  
  The man grabbed a cup
  
  V moves to Agr and then I to get its inflections.

- **In nonfinite sentences**, V is uninflected:
  
  The man wants to / tries to / can [grab a cup]
  
  V doesn’t move.
Movement at LF for a transitive clause

- Spec SUBJECT DP
- Spec OBJECT DP
- Spec SUBJECT DP
- VP
- V
- V'
- AgrP
- Agr'
- Agr
- O-agr features
- S-agr features
- OBJECT DP
- SUBJECT DP
- DP
- Verb movement
- DP-movement
The mapping from LF to PF

At some point during these movements, the PF of the sentence is ‘read off’ the LF tree.

Different orderings of words in different languages reflect the time at which PF is read off from LF.

<table>
<thead>
<tr>
<th>LF</th>
<th>Spec</th>
<th>I</th>
<th>Spec</th>
<th>Agr</th>
<th>Spec</th>
<th>V</th>
<th>DP</th>
</tr>
</thead>
<tbody>
<tr>
<td>English PF</td>
<td>man</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>French PF</td>
<td>man</td>
<td>grab</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maori PF</td>
<td></td>
<td>grab</td>
<td></td>
<td>man</td>
<td></td>
<td>cup</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>man</th>
<th>grab</th>
<th>cup</th>
</tr>
</thead>
<tbody>
<tr>
<td>man</td>
<td>grab</td>
<td>cup</td>
</tr>
<tr>
<td>grab</td>
<td>man</td>
<td>cup</td>
</tr>
</tbody>
</table>
A sensorimotor interpretation of LF

Main idea: the right-branching X-bar structure of LF is an encoding of the representations in successive cycles of the sensorimotor network.
A sensorimotor interpretation of LF

Main idea: the right-branching X-bar structure of LF is an encoding of the representations in successive cycles of the sensorimotor network.
A sensorimotor interpretation of LF

Main idea: the right-branching X-bar structure of LF is an encoding of the representations in successive cycles of the sensorimotor network.
A sensorimotor interpretation of LF

Main idea: the right-branching X-bar structure of LF is an encoding of the representations in successive cycles of the sensorimotor network.
A sensorimotor interpretation of LF

Main idea: the right-branching X-bar structure of LF is an encoding of the representations in successive cycles of the sensorimotor network.
A sensorimotor interpretation of LF

The LF of *The man grabbed the cup* is understood as a rehearsed SM sequence, as follows:

![Diagram of LF for "The man grabbed the cup" showing a sequence of sensorimotor actions and their corresponding syntactic constituents, including IP, DP, AgrP, VP, and V'.]
A sensorimotor interpretation of LF

The LF of *The man grabbed the cup* is understood as a rehearsed SM sequence, as follows:
A sensorimotor interpretation of LF

The LF of *The man grabbed the cup* is understood as a rehearsed SM sequence, as follows:
A sensorimotor interpretation of LF

The LF of *The man grabbed the cup* is understood as a rehearsed SM sequence, as follows:

![Diagram showing the sensorimotor sequence](image-url)
A sensorimotor interpretation of LF

The LF of *The man grabbed the cup* is understood as a rehearsed SM sequence, as follows:
A sensorimotor interpretation of LF

The LF of *The man grabbed the cup* is understood as a rehearsed SM sequence, as follows:
A sensorimotor interpretation of LF

The LF of *The man grabbed the cup* is understood as a rehearsed SM sequence, as follows:
A sensorimotor interpretation of LF

The LF of *The man grabbed the cup* is understood as a rehearsed SM sequence, as follows:
A sensorimotor interpretation of LF

The LF of *The man grabbed the cup* is understood as a rehearsed SM sequence, as follows:

![Diagram of sensorimotor interpretation]
A sensorimotor interpretation of LF

The LF of *The man grabbed the cup* is understood as a rehearsed SM sequence, as follows:

```
attend−man−then−
attend−cup−then−grab
`end`
```
Overlaps between syntactic & SM models

Everything in the LF structure of a transitive clause can be given a natural sensorimotor interpretation.

<table>
<thead>
<tr>
<th>Right-branching X-bar structure</th>
<th>Successive cycles of the SM network</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual X-bar components</td>
<td>Individual representations in the SM network</td>
</tr>
<tr>
<td>DP-movement</td>
<td>Re-attention to agent and patient</td>
</tr>
<tr>
<td>V-movement</td>
<td>Tonic activation of actions in PFC sequence plan</td>
</tr>
</tbody>
</table>
Mapping from LF to PF

Assume: everyone has the same SM sequence for *The man grabbed a cup*.

- But different languages express the proposition using different word orderings.

The mapping from SM to word sequences must be *learned*. The training data is a set of pairs:

- SM sequence (held in episodic buffer)
- Phonological sequence (held in phonological buffer)
An LF-to-PF mapping network

We have built a network which takes training pairs of this sort, and learns word ordering conventions.

• The network’s task is to predict the next word in the input word sequence. (C.f. Elman, Dell, Bock, Chang. . . )

• It achieves this by learning when to generate ‘gaps’ (phonologically empty lexical items).

• The network maintains its own ‘context’ representation, to store the history of words in the sequence.
LF-to-PF mapping network: inputs

`advance phonological buffer`

actual current word

man

cup

grab

c0

attend–man

attend–cup

grab

`end`

attend–man–then–attend–cup–then–grab
LF-to-PF mapping network: inputs

- ‘advance phonological buffer’
- actual current word
- attend–man–then–attend–cup–then–grab
- man
- cup
Noun semantics network

`advance phonological buffer`

- error
- current noun
- noun meaning network
- attend−man−then−
  - attend−cup−then−grab
- man
- cup
- actual current word

'error'

87
Noun sequencing network

- ‘advance phonological buffer’
- error
- current-noun-or-gap
- actual current word
- hidden layer
- current noun
- previous noun
- current context
- noun meaning network

- attend–man–then–attend–cup–then–grab
- man
- cup

88
Results of the noun sequencing network

Training data (for a SVO language):

<table>
<thead>
<tr>
<th>SM sequence</th>
<th>MAN</th>
<th>CUP</th>
<th>MAN</th>
<th>CUP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Word sequence</td>
<td>man</td>
<td>cup</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Network output after training:

<table>
<thead>
<tr>
<th>SM sequence</th>
<th>MAN</th>
<th>CUP</th>
<th>MAN</th>
<th>CUP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Word sequence</td>
<td>man</td>
<td>GAP</td>
<td>GAP</td>
<td>cup</td>
</tr>
</tbody>
</table>
Verb sequencing network

- `advance phonological buffer`
- error
- `current–noun–or–gap`
- `actual current word`
- hidden layer
- `current noun`
- `previous noun`
- `current context`
- noun meaning network

- `attend–man–then–attend–cup–then–grab`

- man
- cup
Verb sequencing network

`advance phonological buffer`

- error
- error

current-noun-or-gap  actual current word  current-infl-verb-or-gap

hidden layer

current noun  previous noun  current context  current inflected verb

noun meaning network  verb meaning network

attend-man-then-attend-cup-then-grab

man  cup
Results of the complete network

Training data (for a SVO language):

<table>
<thead>
<tr>
<th>SM sequence</th>
<th>MAN/GRAB-PLAN</th>
<th>CUP/GRAB-PLAN</th>
<th>MAN/GRAB-PLAN</th>
<th>CUP/GRAB-PLAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Word sequence</td>
<td>man grabbed</td>
<td>cup</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Network output after training:

<table>
<thead>
<tr>
<th>SM sequence</th>
<th>MAN/GRAB-PLAN</th>
<th>CUP/GRAB-PLAN</th>
<th>MAN/GRAB-PLAN</th>
<th>CUP/GRAB-PLAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Word sequence</td>
<td>man/GAP</td>
<td>GAP/GAP</td>
<td>GAP grabbed</td>
<td>cup/GAP</td>
</tr>
</tbody>
</table>

Training data from different languages results in the right kinds of gapping being learned.
Conclusions
Conclusions

Modelling sentence LFs as SM *sequences* permits some interesting new sentence-processing architectures.
Conclusions

Modelling sentence LFs as SM sequences permits some interesting new sentence-processing architectures.

There are some interesting similarities between a sensorimotor model of transitive actions and a Minimalist model of transitive clauses.
Conclusions

Modelling sentence LFs as SM *sequences* permits some interesting new sentence-processing architectures.

There are some interesting similarities between a sensorimotor model of transitive actions and a Minimalist model of transitive clauses.

Maybe Chomskyan syntax is not so weird after all.