Can ACT-R Process Language in Real Time? Putting Together Syntactic and Semantic Processing

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Language Is Complex

Semantics

Syntax

Lexical Access

Perception
Challenge for ACT-R

• Computations are carried out by productions

• Only one production can be executed at once

• Each production takes 50 ms
Our Proposal

INP (INterpretation-based Processing)

Semantic interpretation

Parsing

Words

Reading
INP Is Real-Time

• ACT-R’s subsymbolic, parallel activation-spreading mechanism \( \rightarrow \) speed

• Parsimonious processing, based on “guessing” in advance the interpretation of the sentence \( \rightarrow \) speed

\( \rightarrow \) on-line processing effects
Outline

Introduction and motivation

- Overview of the model
- Syntactic Processing
- Semantic Processing
- Case Study: Text Priming
- Conclusions
The INP Model
(Interpretation-based Processing)

Input sentence (words) ->
Background knowledge

Semantic component

Syntactic component

Interpretation
Semantic and syntactic representations

INP Input sentence

Noah took two animals of each kind on the ark

Napoleon was defeated at Waterloo in 1815

Plato was Socrate’s student
Products of Comprehension

The man read the book

Syntactic representation

Semantic representation
The Interpretation

Interpretation = a known fact that overlaps most with the current sentence

<table>
<thead>
<tr>
<th>“old” information</th>
<th>Sentence</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>At the restaurant the man paid the waiter</em></td>
<td><em>The customer paid the waiter</em></td>
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## The Interpretation

*Interpretation = a known fact that overlaps most with the current sentence*

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<td><em>Thomas Vinterberg directed “The Celebration”</em></td>
<td><em>The person directed a play</em></td>
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More on Interpretation

The interpretation is NOT the meaning of the sentence, but a link with past knowledge

*Thomas Vinterberg directed “The Celebration”*

Background knowledge

*The person directed a play*
More on Interpretation

INP tries to guess the interpretation while it reads the sentence

This sentence is about interpretation

A single “inference”: the interpretation
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The insurance man from Boston drove the student of Physics.
The insurance man from Boston drove the student of Physics.
The insurance man from Boston drove the student of Physics.
The Syntactic Processor: Summary

• Builds the syntactic and semantic representation
• Forms complex meanings from simple meanings (e.g., insurance-man-from-Boston)
• Repairs wrong syntactic assignments (but not semantic-role assignments)
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The Semantic Processor

The job of the semantic processor is to find an interpretation as it receives meanings and semantic roles from the syntactic processor.

Input sentence

Syntactic processor

interpretation

meanings +
semantic roles

Semantic processor

interpretation
Semantic Processing

Assume known: 🌟 = *The insurance man drove his friends*

*The insurance man* from Boston drove the student of Physics

Meaning1 (Role: ?)  Meaning1 (Role: ?)  drove (Role: verb)  Meaning2 (Role: patient)  <end>

Interpr: 🌟  Interpr: 🌟  Interpr: 🌟  Interpr: 🌟  Retrieve Past interpretation

🌟 connects the sentence to the past knowledge
Semantic Processing: Internals

Search-and-match process:

• Search for an interpretation

• Match the interpretation against the current word
• Parallel, subsymbolic activation spreading processes enable high speed

• Activation spreading associations semantic similarities (set as LSA distances)
Does Semantics Affect Syntax?

• Domain: syntactic ambiguity
  
  \textit{The spy saw the man with the binoculars}

• Traditionally, robust verb-attachment preference
  
  \textit{The spy saw the man with the revolver.}

• Question: does the interpretation help make decisions in syntactic-ambiguity cases?
Syntax-Semantics Experiment

NP-passage

She inspected the vase that she wanted to give to her mother

VP-passage

She inspected the vase to see the gold mark

Targets:

She inspected the vase for her mother once again (NP)
She inspected the vase for the mark once again (VP)

Results: targets congruent with passages are fastest
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Case Study: Text Priming  
(Schwanenflugel & White, 1991)

• Lexical decision after reading a passage
• Passages containing one major theme or two themes (one major, one minor)
• Expectancy of target: with respect to major or minor theme
• Result for people and model:
  – priming effect of major theme (i.e., paragraph context): larger
  – priming effect of minor theme (i.e., local context): smaller

Explanation:

major script \[\rightarrow\] Interpretation \[\rightarrow\] RT

minor script
Case Study: Text Priming
(Schwanenflugel & White, 1991)

The equipment they carried was heavy. They had gotten an early start at dawn. It had been a long day for the guys.

**Major-theme passage**

The hiking trip was the most strenuous the group had had.

**Minor-theme passage**

After a treacherous hike, Bill and his friends sluggishly entered their apartment lobby.

*The hikers slowly climbed up the*

Target words

**Major-consistent**

- mountain

**Minor-consistent**

- stairs
Text Priming: Data and Model

Differences in lexical decision latencies (ms)

Differences are with respect to the neutral context. Positive = faster than neutral
Lexical Decision

Extract the meaning of the target string
- success of retrieval: word
- failure of retrieval: nonword

More activation $\Rightarrow$ faster response time
Locality of Interpretation

Text

\{ Sentence1, Sentence2 \}

Interpretation1

\text{script}

Interpretation2
The hiking trip was the most strenuous the group had had. The hikers slowly climbed up the mountain. The hikers slowly climbed up the mountain.

The equipment they carried was heavy. [...] The friends sluggishly entered the apartment lobby. The people climbed up the stairs. The hikers climbed up the stairs.

The equipment they carried was heavy. [...]
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INP and the Real World

• Limited parsing
• Accuplacer reading comprehension test
  – Multiple-choice questions (4 choices)
  – INP: about 60% correct
• Psychology textbook questions
  – Multiple-choice questions and true/false questions
  – INP: about 80%
• LSA for word similarities
Summary

• Real time language processing (from parsing to semantic interpretation) can be achieved by virtue of the parallel, subsymbolic mechanisms of ACT-R.

• Guessing in advance the interpretation of the sentence enables our model to capture on-line language processing effects.