An Inference-rules based Categorial Grammar Learner for Simulating Language Acquisition

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   Combinatory Categorial Grammar
   Language Acquisition

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   Grammar Induction by Inference Rules
   The Learning Architecture

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   Learning an Artificial Grammar
   Learning Auxiliary Verb Fronting
   Learning Correct Word Order

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Categorial Grammar

- **basic categories**: $S$ (sentence), $NP$ (noun phrase), $N$ (noun)
- **Complex categories**: $NP/N$, $S\backslash NP$ and $(S\backslash NP)\backslash(S\backslash NP)$
- **Slash operators**: / \ 

Peter saw a book

\[
\begin{array}{cccc}
NP & VP & DT & N \\
\hline
\end{array}
\]

\[
\begin{array}{cccc}
NP \\
\hline
VP \\
\hline
S \\
\end{array}
\]

\[
\begin{array}{cccccc}
NP & (S\backslash NP)/NP & NP/N & N & NP \\
\hline
S\backslash NP \rightarrow S \\
\end{array}
\]

Figure: Example derivation for sentence *Peter saw a book*
Categorial Grammar

- basic categories: $S$ (sentence), $NP$ (noun phrase), $N$ (noun)
- Complex categories: $NP/N$, $(S\backslash NP)\backslash(S\backslash NP)$
- Slash operators: / \ 

Figure: Example derivation for sentence *Peter saw a book*
Different Operation Rules

- **Function application rules (CG)**
  - Forward: $A/B \quad B \quad \rightarrow \quad A \quad (>)$
  - Backward: $B \quad A\backslash B \quad \rightarrow \quad A \quad (<)$

- **Function composition rules (CCG)**
  - Forward: $A/B \quad B/C \quad \rightarrow \quad A/C \quad (> B)$
  - Backward: $B\backslash C \quad A\backslash B \quad \rightarrow \quad A\backslash C \quad (< B)$

- **Type raising rules (CCG)**
  - Forward: $A \quad \rightarrow \quad T/(T\backslash A) \quad (> T)$
  - Backward: $A \quad \rightarrow \quad T\backslash(T/A) \quad (< T)$

- **Substitution rules (CCG)**
  - Forward: $(A/B)/C \quad B/C \quad \rightarrow \quad A/C \quad (>S)$
  - Backward: $B\backslash C \quad (A\backslash B)\backslash C \quad \rightarrow \quad A\backslash C \quad (<S)$
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Nativist vs. Empiricist

- Auxiliary Verb Fronting
  - Peter is awake.
  - Is Peter awake?
  - Peter who is sleepy is awake.
    - Is Peter who is sleepy awake?
    - *Is Peter who sleepy is awake?

- Word Order
  - I should go.
  - I have gone.
  - I am going.
  - I have been going.
  - I should have gone.
  - I should be going.
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  - *I have should been going.
Nativist vs. Empiricist

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Research Questions

1. Can we give a computational simulation of the acquisition of syntactic structures?
   - How do we derive the category of an unknown word in a sentence?

2. Can we give a judgement of the Nativist-Empiricist debate from the perspective of CCG?
   - How important is experience? Or the innate ability is more important?
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Level 0/1 Inference Rules

- Level 0 inference rules
  \[ \frac{B/A \quad X \quad \rightarrow \quad B}{\Rightarrow \quad X = A \quad \text{if} A \neq S} \]
  \[ \frac{X \quad B\setminus A \quad \rightarrow \quad B}{\Rightarrow \quad X = A \quad \text{if} A \neq S} \]

- Level 1 inference rules
  \[ \frac{A \quad X \quad \rightarrow \quad B}{\Rightarrow \quad X = B\setminus A \quad \text{if} A \neq S} \]
  \[ \frac{X \quad A \quad \rightarrow \quad B}{\Rightarrow \quad X = B/A \quad \text{if} A \neq S} \]

Figure: Example of level 1 inference rules: Peter works.

\[ \overline{\text{NP}} \quad \overline{\text{X}} \]
\[ (S\setminus \text{NP}) \]
\[ \frac{S}{<} \]
Level 2 Inference Rules

- Level 2 side inference rules
  \[\mathbf{X} \quad \mathbf{A} \quad \mathbf{B} \quad \rightarrow \quad \mathbf{C} \quad \Rightarrow \quad \mathbf{X} = (\mathbf{C} / \mathbf{B}) / \mathbf{A}\]
  \[\mathbf{A} \quad \mathbf{B} \quad \mathbf{X} \quad \rightarrow \quad \mathbf{C} \quad \Rightarrow \quad \mathbf{X} = (\mathbf{C} \setminus \mathbf{A}) \setminus \mathbf{B}\]

- Level 2 middle inference rule
  \[\mathbf{A} \quad \mathbf{X} \quad \mathbf{B} \quad \rightarrow \quad \mathbf{C} \quad \Rightarrow \quad \mathbf{X} = (\mathbf{C} \setminus \mathbf{A}) / \mathbf{B}\]

Figure: Example of level 2 inference rules: Peter saw a book.
Level 3 Inference Rules

- Level 3 side inference rules
  \[ X \quad A \quad B \quad C \rightarrow D \Rightarrow X = ((D/C)/B)/A \]
  \[ A \quad B \quad C \quad X \rightarrow D \Rightarrow X = ((D\backslash A)\backslash B)\backslash C \]

- Level 3 middle inference rules
  \[ A \quad X \quad B \quad C \rightarrow D \Rightarrow X = ((D\backslash A)/C)/B \]
  \[ A \quad B \quad X \quad C \rightarrow D \Rightarrow X = ((D\backslash A)\backslash B)/C \]

- Inference rules of up to level 3 can derive most categories of common English words.
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Figure: Learning process using inference rules
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Target Grammar

\[
\begin{align*}
Peter & := \text{NP} \quad \text{with} \quad := (\text{N}/\text{N})/\text{NP} \\
Mary & := \text{NP} \quad \text{with} \quad := (\text{NP}/\text{NP})/\text{NP} \\
big & := \text{N}/\text{N} \quad \text{with} \quad := ((\text{S}/\text{NP})\backslash(\text{S}/\text{NP}))/\text{NP} \\
\text{colorless} & := \text{N}/\text{N} \quad \text{sleep} := \text{S}\backslash\text{NP} \\
book & := \text{N} \quad a := \text{NP}/\text{N} \\
\text{telescope} & := \text{N} \quad \text{give} := ((\text{S}/\text{NP})/\text{NP})/\text{NP} \\
\text{the} & := \text{NP}/\text{N} \quad \text{saw} := (\text{S}/\text{NP})/\text{NP} \\
run & := \text{S}\backslash\text{NP} \quad \text{read} := (\text{S}/\text{NP})/\text{NP} \\
big & := \text{N}/\text{N} \quad \text{furiously} := ((\text{S}/\text{NP})\backslash(\text{S}/\text{NP})) \\
\end{align*}
\]

Table: Target Grammar Rules

- Recursive & ambiguous
- Assume only NP and N are known to the learner
Result

Figure: Two ambiguous parses of the sentence
Peter saw Mary with a big big telescope

Figure: Ambiguous parse 1
Peter saw Mary with a big big telescope

Figure: Ambiguous parse 2
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Learning Auxiliary Verb Fronting 1

**Figure:** Learning Auxiliary Verb Fronting 1

Peter is sleepy

\[ \begin{array}{c}
NP \quad (S/\text{NP})/(S_{adj}/\text{NP}) \\
S_{adj}/\text{NP} \\
S/\text{NP} \\
\end{array} \]

Peter awake

\[ \begin{array}{c}
NP \quad (S_{q}/(S_{adj}/\text{NP}))/\text{NP} \\
S_{adj}/\text{NP} \\
S_{q}/(S_{adj}/\text{NP}) \\
\end{array} \]

Peter who is sleepy is awake

\[ \begin{array}{c}
NP \quad (\text{NP}/\text{NP})/(\text{S}/\text{NP}) \\
(\text{S}/\text{NP})/(S_{adj}/\text{NP}) \\
S_{adj}/\text{NP} \\
S/\text{NP} \\
\end{array} \]

\[ \begin{array}{c}
NP \quad (\text{NP}/(S_{adj}/\text{NP}))/\text{NP} \\
S_{adj}/\text{NP} \\
S/\text{NP} \\
\end{array} \]

\[ \begin{array}{c}
NP \\
\text{NP} \\
\text{NP} \\
\end{array} \]
Learning Auxiliary Verb Fronting 2

\[
\begin{align*}
\text{Is} & := (S/adj/NP)/NP \\
\text{Peter} & := (NP/NP)/(S/NP) \\
\text{who} & := (S/NP)/(S/adj/NP) \\
\text{is} & := S/adj/NP \\
\text{sleepy} & := S/adj/NP \\
\text{awake} & := (S_q/(S/adj/NP))/NP
\end{align*}
\]

\textbf{Figure:} Learning Auxiliary Verb Fronting 2

- \textit{is} := (S/NP)/(S/adj/NP)
- \textit{Is} := (S_q/(S/adj/NP))/NP
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*Figure: Learning Correct Word Order*
1. Can we give a computational simulation of the acquisition of syntactic structures?
   - How do we derive the category of an unknown word in a sentence?
   - This paper presents a simple and intuitive method to achieve this.

2. Can we give a judgement of the Nativist-Empiricist debate from the perspective of CCG?
   - How important is experience? Or the innate ability is more important?
   - Simple and intuitive logical rules can also help resolve the celebrated linguistic phenomena.
   - Logic gives a third way beside experience and innateness.
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