

# An Inference-rules based Categorical Grammar Learner for Simulating Language Acquisition

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# Outline

## Introduction

Combinatory Categorical Grammar  
Language Acquisition

## Learning by Inference Rules

Grammar Induction by Inference Rules  
The Learning Architecture

## Experiment

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

## Conclusion



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# Categorial Grammar

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

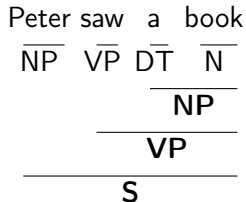


Figure: Example derivation for sentence *Peter saw a book*





## Different Operation Rules

- Function application rules (CG)

Forward  $A/B \quad B \rightarrow A \quad (>)$

Backward  $B \quad A \setminus B \rightarrow A \quad (<)$

- Function composition rules (CCG)

Forward  $A/B \quad B/C \rightarrow A/C \quad (> \mathbf{B})$

Backward  $B \setminus C \quad A \setminus B \rightarrow A \setminus C \quad (< \mathbf{B})$

- Type raising rules (CCG)

Forward  $A \rightarrow T/(T \setminus A) \quad (> \mathbf{T})$

Backward  $A \rightarrow T \setminus (T/A) \quad (< \mathbf{T})$

- Substitution rules (CCG)

Forward  $(A/B)/C \quad B/C \rightarrow A/C \quad (> \mathbf{S})$

Backward  $B \setminus C \quad (A \setminus B) \setminus C \rightarrow A \setminus C \quad (< \mathbf{S})$

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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.
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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

$$B/A \quad \mathbf{X} \quad \rightarrow \quad B \quad \Rightarrow \quad \mathbf{X} = A \quad \text{if } A \neq S$$

$$\mathbf{X} \quad B \setminus A \quad \rightarrow \quad B \quad \Rightarrow \quad \mathbf{X} = A \quad \text{if } A \neq S$$

- Level 1 inference rules

$$A \quad \mathbf{X} \quad \rightarrow \quad B \quad \Rightarrow \quad \mathbf{X} = B \setminus A \quad \text{if } A \neq S$$

$$\mathbf{X} \quad A \quad \rightarrow \quad B \quad \Rightarrow \quad \mathbf{X} = B/A \quad \text{if } A \neq S$$

$$\begin{array}{c} \text{Peter} \quad \text{works} \\ \hline \text{NP} \quad \mathbf{X} \\ \text{(S} \setminus \text{NP)} \\ \hline \text{S} \end{array} \leftarrow$$

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

## Level 2 Inference Rules

- Level 2 side inference rules

$$\mathbf{X} \ A \ B \rightarrow C \Rightarrow \mathbf{X} = (C/B)/A$$

$$A \ B \ \mathbf{X} \rightarrow C \Rightarrow \mathbf{X} = (C \setminus A) \setminus B$$

- Level 2 middle inference rule

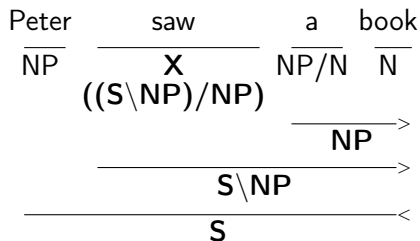
$$A \ \mathbf{X} \ B \rightarrow C \Rightarrow \mathbf{X} = (C \setminus A) / B$$


Figure: Example of level 2 inference rules: *Peter saw a book.*

## Level 3 Inference Rules

- Level 3 side inference rules

$$\mathbf{X} \ A \ B \ C \rightarrow D \Rightarrow \mathbf{X} = ((D/C)/B)/A$$

$$A \ B \ C \ \mathbf{X} \rightarrow D \Rightarrow \mathbf{X} = ((D \setminus A) \setminus B) \setminus C$$

- Level 3 middle inference rules

$$A \ \mathbf{X} \ B \ C \rightarrow D \Rightarrow \mathbf{X} = ((D \setminus A)/C)/B$$

$$A \ B \ \mathbf{X} \ C \rightarrow D \Rightarrow \mathbf{X} = ((D \setminus A) \setminus B)/C$$

- Inference rules of up to level 3 can derive most categories of common English words.



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# The Learning Architecture

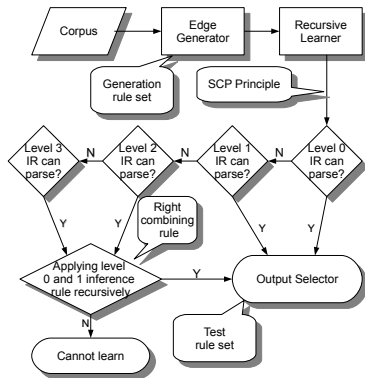


Figure: Learning process using inference rules

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## Target Grammar

<i>Peter</i>	$:=$ NP	<i>with</i>	$:=$ (N\N)/NP
<i>Mary</i>	$:=$ NP	<i>with</i>	$:=$ (NP\NP)/NP
<i>big</i>	$:=$ N/N	<i>with</i>	$:=$ ((S\NP)\(S\NP))/NP
<i>colorless</i>	$:=$ N/N	<i>sleep</i>	$:=$ S\NP
<i>book</i>	$:=$ N	<i>a</i>	$:=$ NP/N
<i>telescope</i>	$:=$ N	<i>give</i>	$:=$ ((S\NP)/NP)/NP
<i>the</i>	$:=$ NP/N	<i>saw</i>	$:=$ (S\NP)/NP
<i>run</i>	$:=$ S\NP	<i>read</i>	$:=$ (S\NP)/NP
<i>big</i>	$:=$ N/N	<i>furiously</i>	$:=$ (S\NP)\(S\NP)

Table: Target Grammar Rules

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

## Result

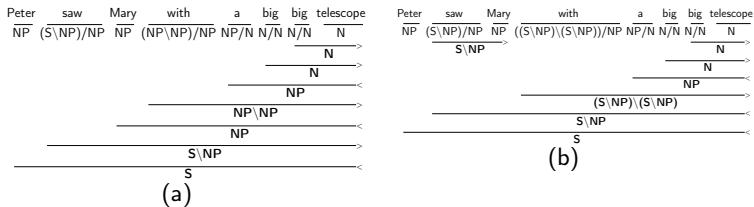


Figure: Two ambiguous parses of the sentence



## Result

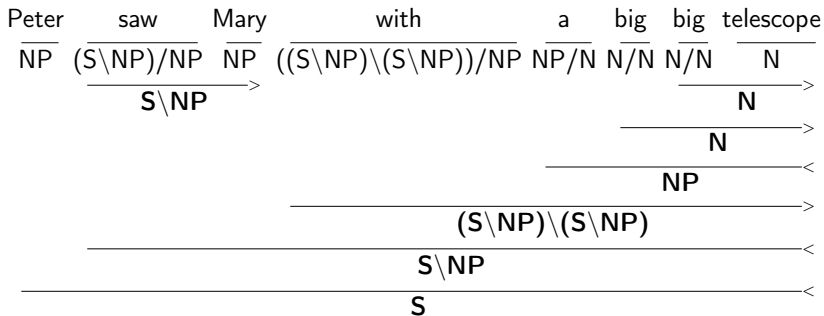


Figure: Ambiguous parse 2

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# Learning Auxiliary Verb Fronting 1

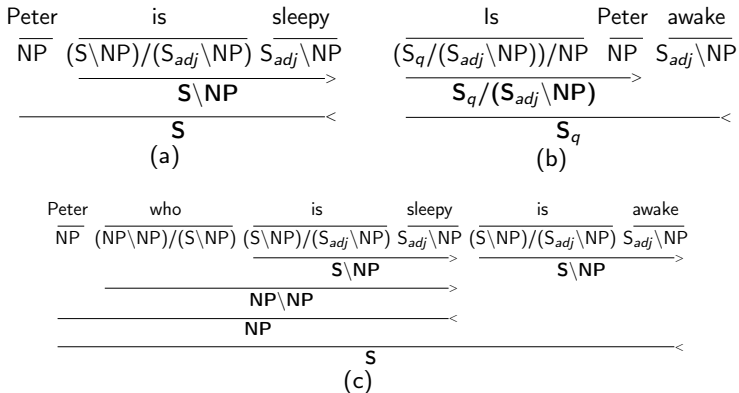


Figure: Learning Auxiliary Verb Fronting 1

## Learning Auxiliary Verb Fronting 2

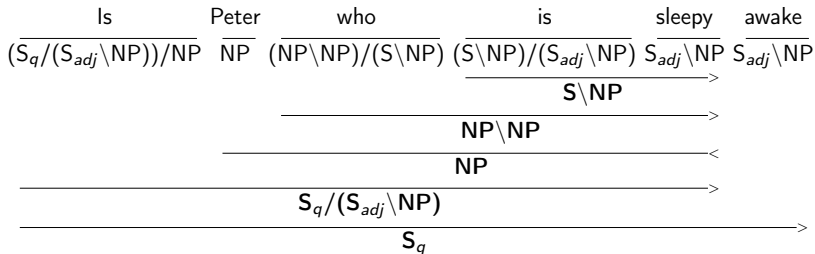


Figure: Learning Auxiliary Verb Fronting 2

- $is := (S\backslash NP)/(S_{adj}\backslash NP)$   
 $is := (S_q/(S_{adj}\backslash NP))\backslash NP$

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## Learning Correct Word Order

- I should go.
- I have gone.
- I am going.
- I have been going.
- I should have gone.
- I should be going.
- I should have been going.
- \*I have should been going.

*should* :=  $(S_s \setminus NP) / (S \setminus NP)$

*should* :=  $(S_s \setminus NP) / (S_h \setminus NP)$

*should* :=  $(S_s \setminus NP) / (S_b \setminus NP)$

*have* :=  $(S_h \setminus NP) / (S \setminus NP)$

*have* :=  $(S_h \setminus NP) / (S_b \setminus NP)$

*be* :=  $(S_b \setminus NP) / (S \setminus NP)$

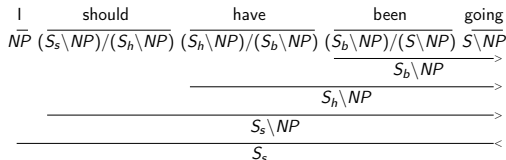


Figure: Learning Correct Word Order

# Conclusion

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.



