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

Xuchen Yao, Jianqiang Ma, Sergio Duarte, Çağrı Çöltekin

University of Groningen

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Outline

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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: / \

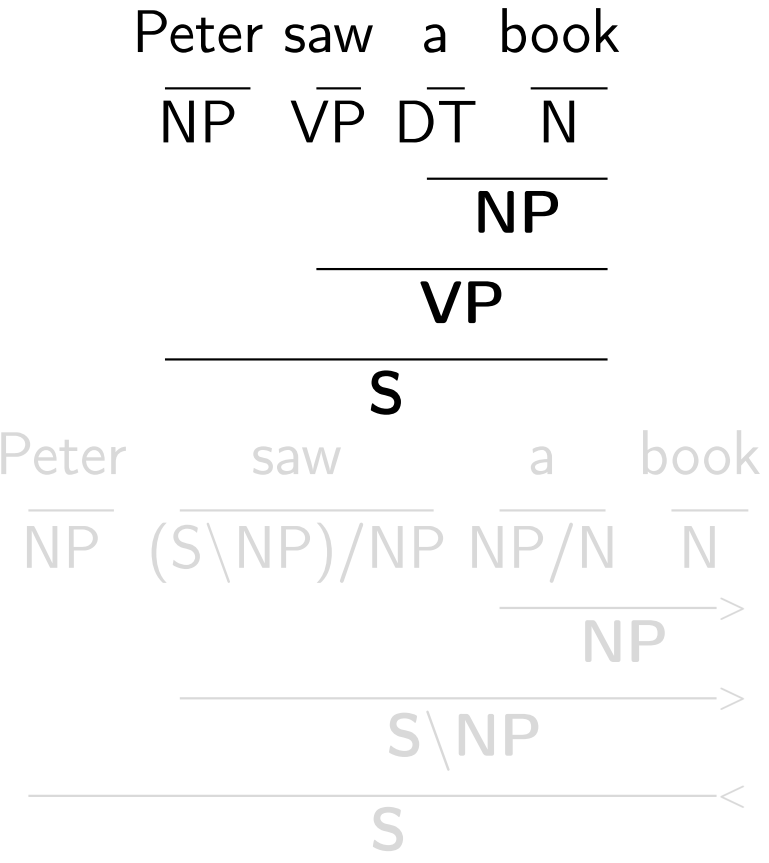

Figure: Example derivation for sentence *Peter saw a boo*

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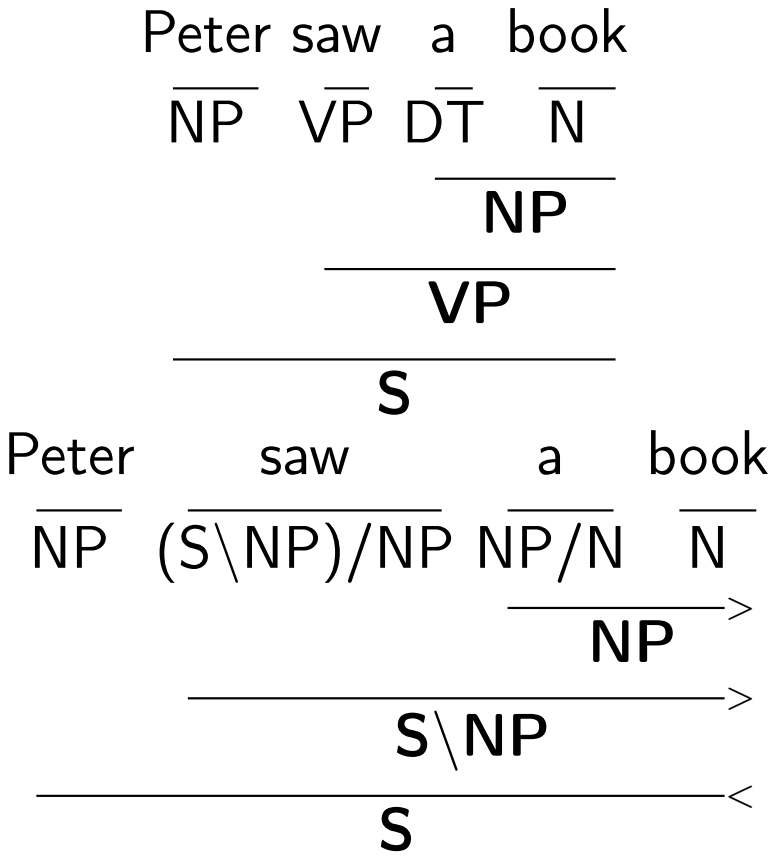

Figure: Example derivation for sentence *Peter saw a book*.

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Different Operation Rules

- Function application rules (CG)

Forward	A/B	B	$\rightarrow$	A	$(>)$
Backward	B	$A\backslash B$	$\rightarrow$	A	$(<)$

- Function composition rules (CCG)

Forward	A/B	B/C	$\rightarrow$	A/C	$(>\mathbf{B})$
Backward	$B\backslash C$	$A\backslash B$	$\rightarrow$	$A\backslash C$	$(<\mathbf{B})$

- Type raising rules (CCG)

Forward	A	$\rightarrow$	$T/(T\backslash A)$		$(>\mathbf{T})$
Backward	A	$\rightarrow$	$T\backslash(T/A)$		$(<\mathbf{T})$

- Substitution rules (CCG)

Forward	$(A/B)/C$	B/C	$\rightarrow$	A/C	$(>\mathbf{S})$
Backward	$B\backslash C$	$(A\backslash B)\backslash C$	$\rightarrow$	$A\backslash C$	$(<\mathbf{S})$

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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

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

- Level 1 inference rules

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

$$\dfrac{\dfrac{\text{Peter}}{\text{NP}} \quad \dfrac{\textbf{works}}{\dfrac{\mathbf{X}}{\mathbf{(S\backslash NP)}}}}{\mathbf{S}}<$$

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

Level 2 Inference Rules

- Level 2 side inference rules

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

- Level 2 middle inference rule

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

$$\dfrac{\text{Peter}}{\text{NP}} \quad \dfrac{\dfrac{\text{saw}}{\mathbf{((S\backslash NP)/NP)}} \quad \dfrac{\dfrac{\text{a}}{\text{NP/N}} \quad \dfrac{\text{book}}{\text{N}}}{\mathbf{NP}}>}{\mathbf{S\backslash NP}}>}{\mathbf{S}}<$$

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

Level 3 Inference Rules

- Level 3 side inference rules

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

- Level 3 middle inference rules

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

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

Outline

The Learning Architecture

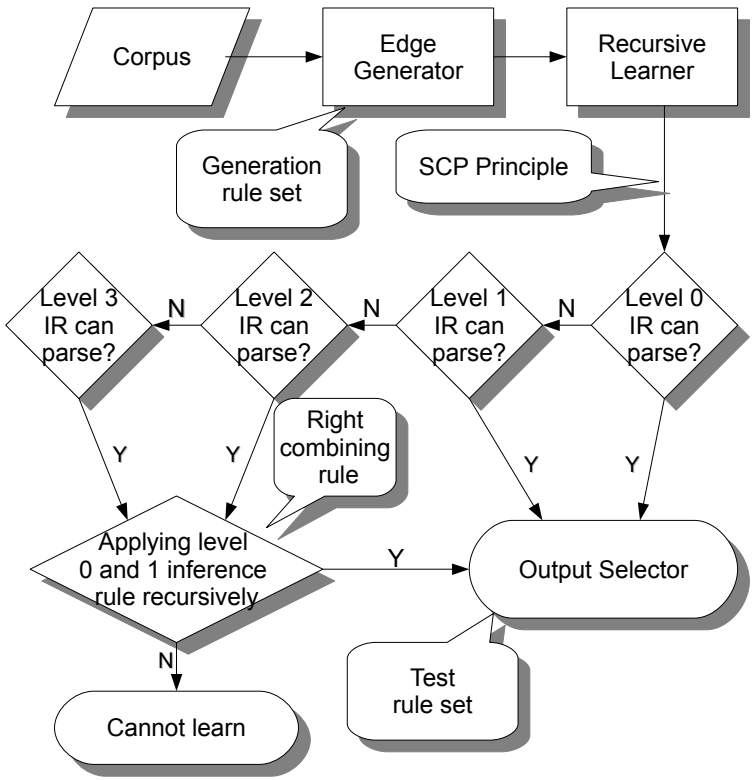

Figure: Learning process using inference rules

Outline

Target Grammar

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

Table: Target Grammar Rules

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

Result

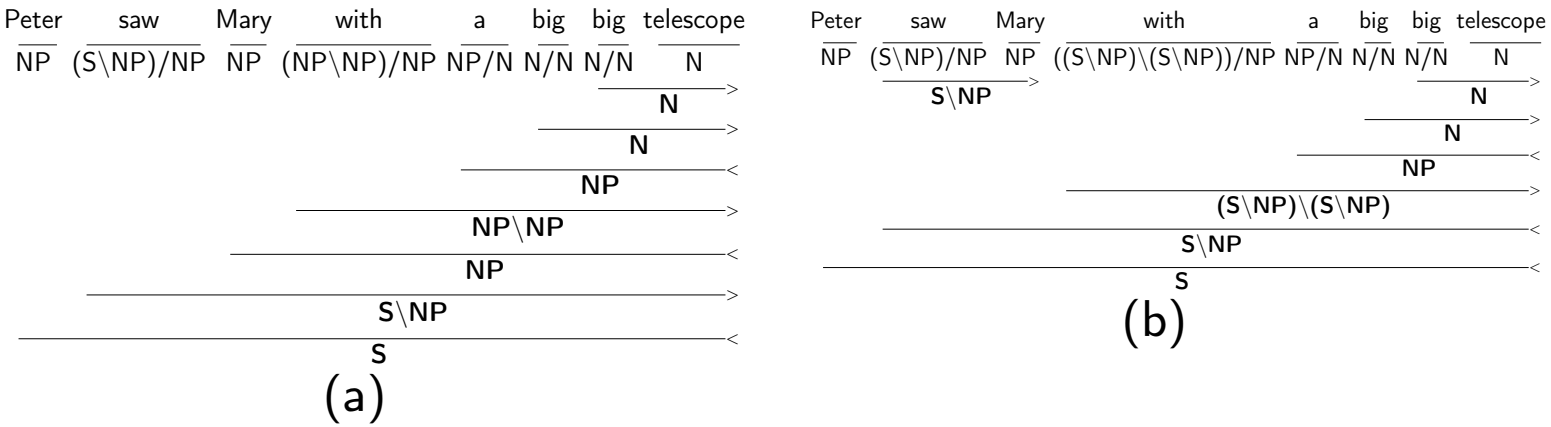

Figure: Two ambiguous parses of the sentence

Result

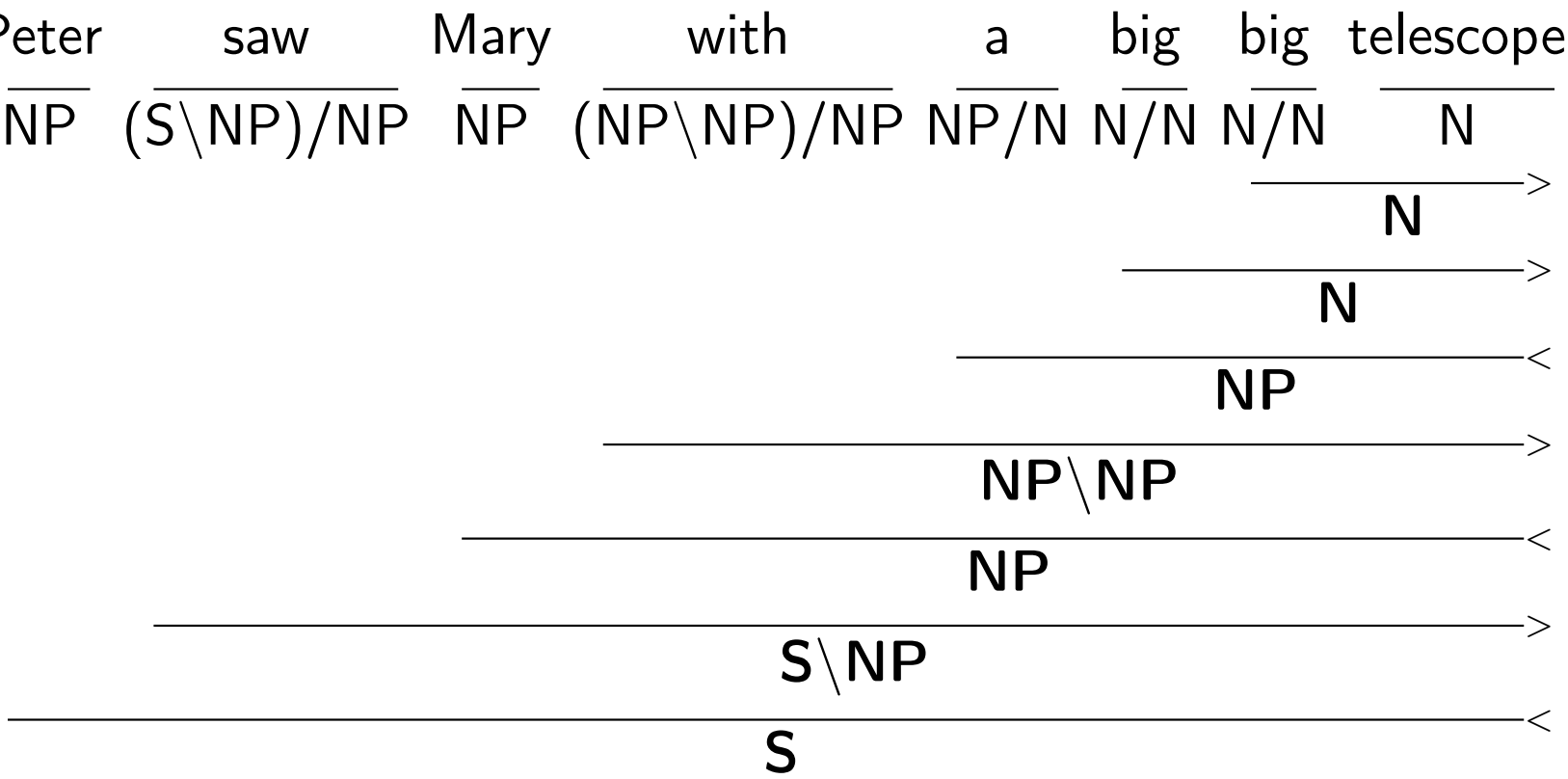

Figure: Ambiguous parse 1

Result

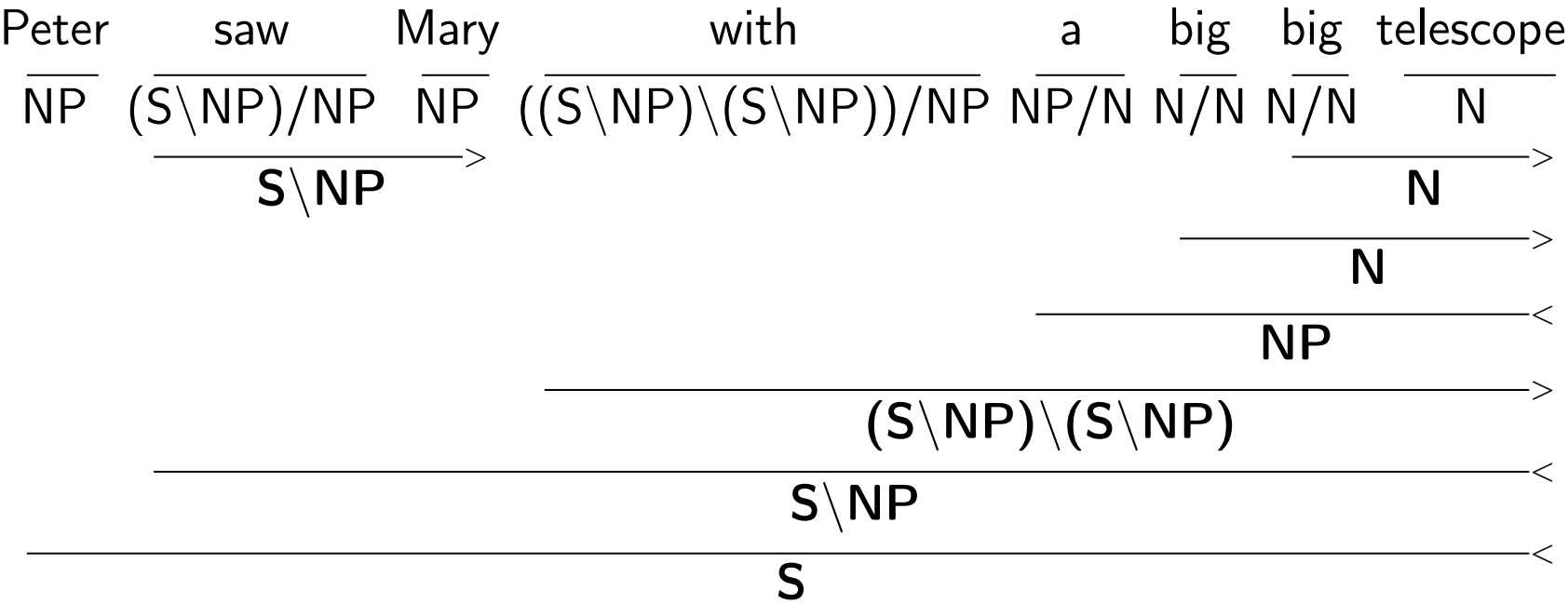

Figure: Ambiguous parse 2

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Learning Auxiliary Verb Fronting 1

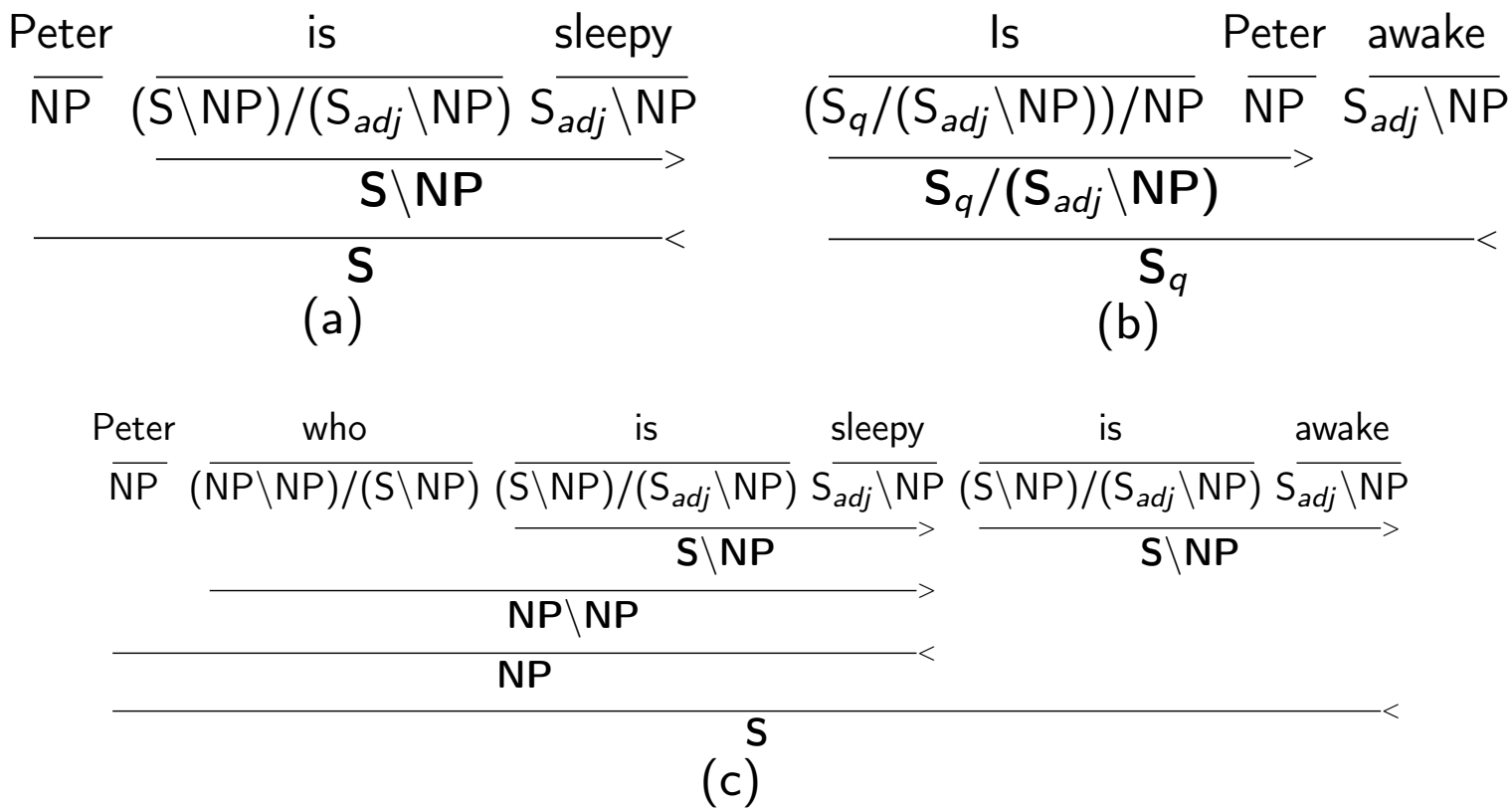

Figure: Learning Auxiliary Verb Fronting 1

Learning Auxiliary Verb Fronting 2

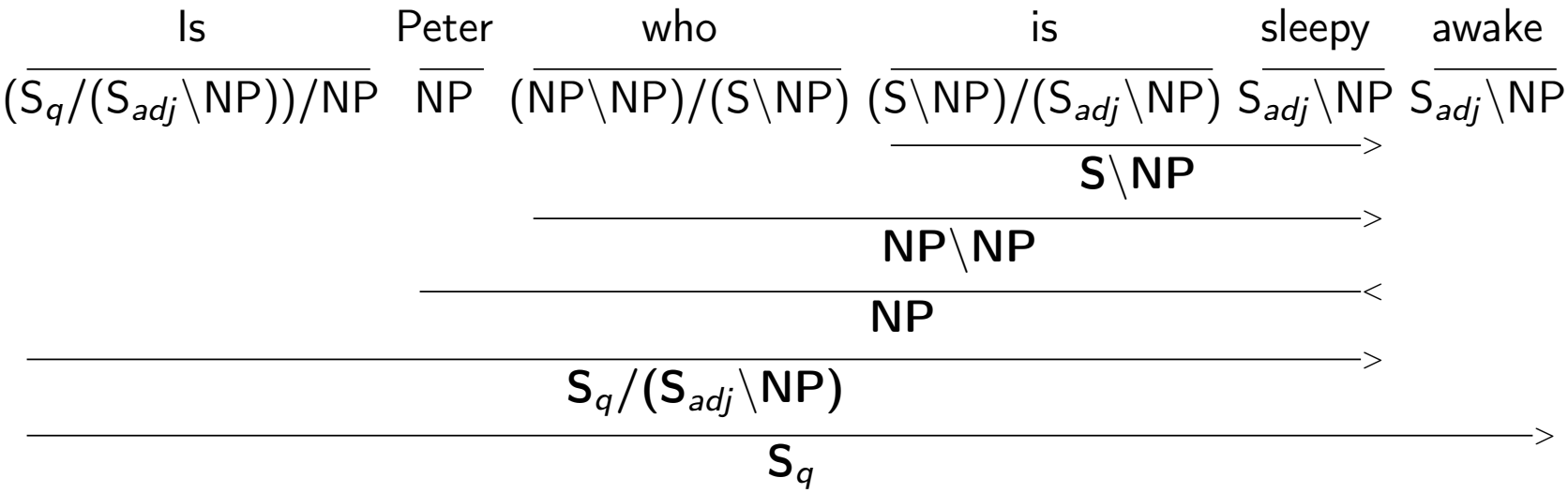

Figure: Learning Auxiliary Verb Fronting 2

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

Outline

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.
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$$
\begin{aligned}
\textit{should} &:= (S_s \backslash NP)/(S \backslash NP) \\
\textit{should} &:= (S_s \backslash NP)/(S_h \backslash NP) \\
\textit{should} &:= (S_s \backslash NP)/(S_b \backslash NP) \\
\textit{have} &:= (S_h \backslash NP)/(S \backslash NP) \\
\textit{have} &:= (S_h \backslash NP)/(S_b \backslash NP) \\
\textit{be} &:= (S_b \backslash NP)/(S \backslash NP)
\end{aligned}
$$

$$
\dfrac{\dfrac{\dfrac{\dfrac{\text{I}}{NP} \quad \dfrac{\text{should}}{(S_s \backslash NP)/(S_h \backslash NP)} \quad \dfrac{\dfrac{\text{have}}{(S_h \backslash NP)/(S_b \backslash NP)} \quad \dfrac{\dfrac{\text{been}}{(S_b \backslash NP)/(S \backslash NP)} \quad \dfrac{\text{going}}{S \backslash NP}}{S_b \backslash NP}\,>}{S_h \backslash NP}\,>}{S_s \backslash NP}\,>}{S_s}\,<
$$

Figure: Learning Correct Word Order

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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.

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