

Parsing as Deduction

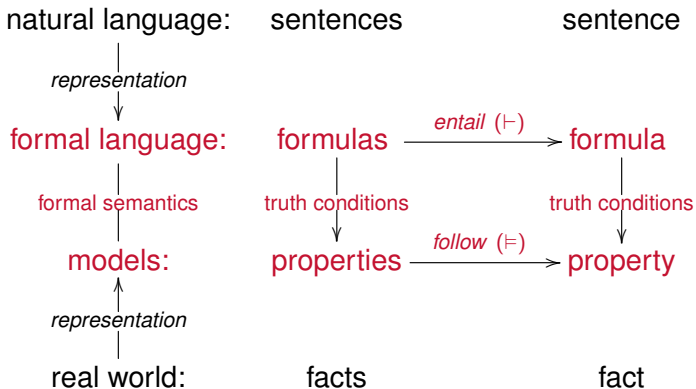
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Institute of Computer Science and Technology
Peking University

November 22, 2017

Language, **Logic** and Computation

Recap: The general picture



Recap: Language and Inference

We want to say something

Given a set of symbols $N = \{A, B, C, D, \dots\}$, let L_{All} be the set of finite strings (*formulas*, sentences) of the following shape:

- $All(X, Y)$ (where $X, Y \in N$)

The *intended reading* of $All(X, Y)$ is *All X are Y*.

We are interested in inference

Given the intended reading, the following reasoning pattern sounds reasonable (for any $X, Y \in N$):

$$\frac{All(X, Y) \quad All(Y, Z)}{All(X, Z)} \text{ Trans} \qquad \frac{}{All(X, X)} \text{ Id}$$

We are interested in what sentences can be derived from what premises according to the inference system.

Recap: Proof

Given the set of premises:

$$\Gamma = \{\text{All}(A, B), \text{All}(B, C), \text{All}(C, B), \text{All}(C, D)\}$$

$$\frac{\frac{\text{All}(A, B) \quad \text{All}(B, C)}{\text{All}(A, C)} \text{ (Trans)} \quad \text{All}(C, D)}{\text{All}(A, D)} \text{ (Trans)}$$

We can turn the **tree** into a linear form (like a math proof).

- 1 $\text{All}(A, B)$ (Γ)
- 2 $\text{All}(B, C)$ (Γ)
- 3 $\text{All}(A, C)$ (Trans (1)(2))
- 4 $\text{All}(C, D)$ (Γ)
- 5 $\text{All}(A, D)$ (Trans (3)(4))

Recap: First-order languages

A *signature* (符号表) gives the *non-logical* symbols:

- variables (变元) $x, y \dots \in Var$
- constants (常元) $c, d \dots \in Con$
- predicate symbols (谓词符号) $P, Q \dots$ each has an arity
- function symbols (函数符号) $f, g \dots$ each has an arity

Given this signature the first-order language is defined as:

term (项) $t ::= x \mid c \mid f(\vec{t})$ where $x \in Var, c \in Con$

formula $\phi ::= t \equiv t \mid P\vec{t} \mid \neg\phi \mid (\phi \rightarrow \phi) \mid \forall x\phi$

Syllogisms can be expressed

- Some A is B : $\exists x(A(x) \wedge B(x))$
- No A is B : $\forall x(A(x) \rightarrow \neg B(x))$

$\exists x$ is defined as $\neg\forall x\neg$.

Language, Logic and **Computation**

Computational Linguistics

Wikipedia



Computational linguistics is an **interdisciplinary** field concerned with the **statistical** or **rule-based** modeling of **natural language** from a **computational perspective**.

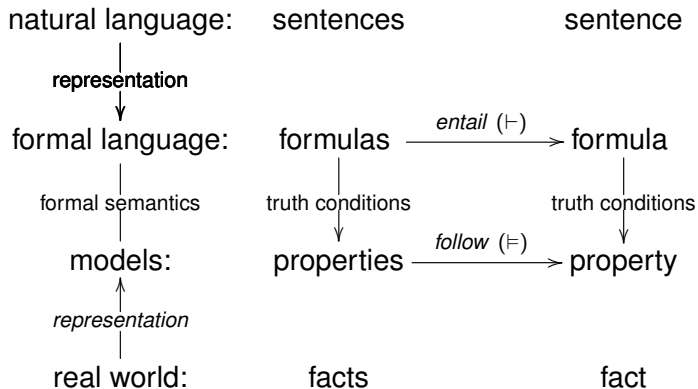
Natural Language Understanding

Natural language sentences \Rightarrow **Formal language** *sentences*

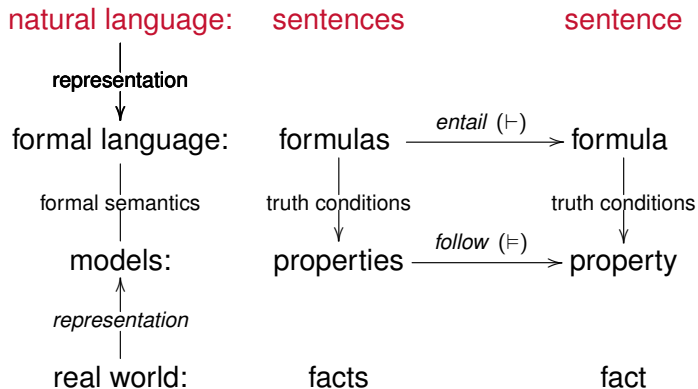
Natural Language Generation

Formal language *sentences* \Rightarrow **Natural language** sentences

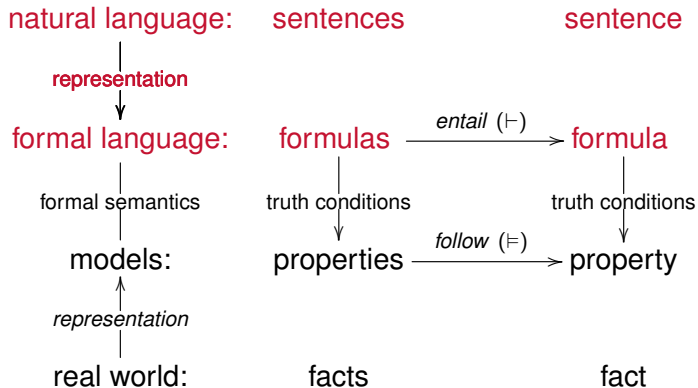
The general picture



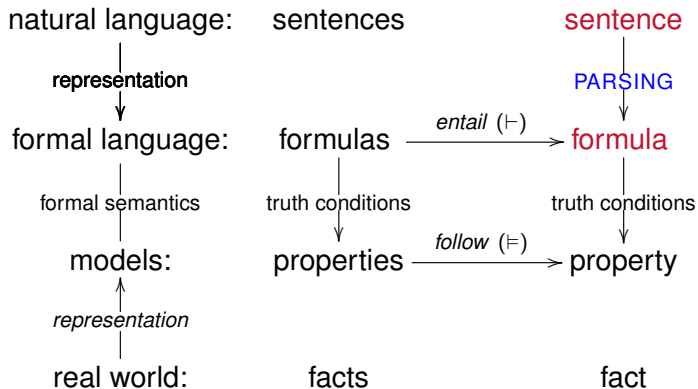
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Syntactic parsing

Parsing = making **explicit structure** that is **implicit in natural language strings**

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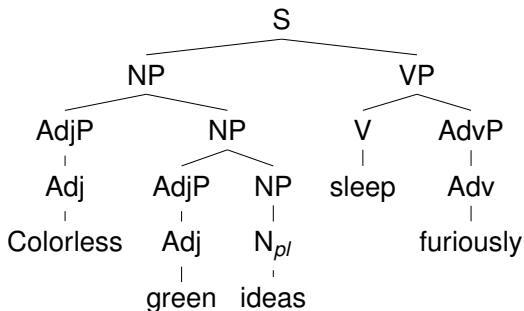
Input: colorless green ideas sleep furiously

Syntactic parsing

Parsing = making **explicit structure** that is **implicit in natural language strings**

Input: colorless green ideas sleep furiously

Output:



Using a CFG

Parsing:

Given a grammar G and a string s the parsing problem answers the question **whether or not** $s \in L(G)$. If $s \in L(G)$, we are interested in its **parse tree** (or say derivation).

$$G = (V, T, P, S)$$

Using a CFG

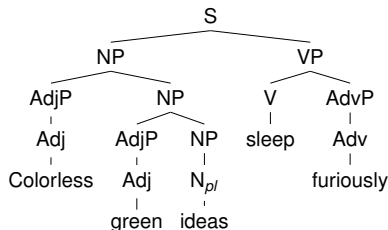
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$$G = (V, T, P, S)$$

A **parse tree** for a grammar G is a tree where:

- The root is S .
- The interior nodes are the nonterminals from V and the children of a node N correspond to some production rule in P .
- The leaf nodes are the terminal symbols in T .



Programming language

```
System.out.println("Welcome to Java!");

int sum = 0, i = 1;
while (i < 10) {
    sum = sum + i;
    i++;
}
System.out.println("0+1+2+...+9 is " + sum);

System.out.print("Enter the radius: ");
double radius = input.nextDouble();

// Compute area
double area = radius * radius * 3.14159;

// Display results
System.out.println("The area for the circle is " + area);
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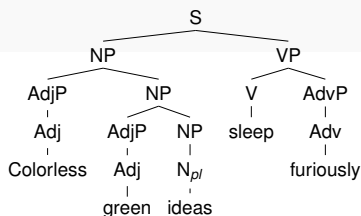
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Easy to parse. Designed that way!

Parsing Natural Language Sentences: Ideas

Top-down vs. Bottom-up



Goal-driven/top-down:

- Start with the **START** symbol
- Derive sentential forms
If the string is among the sentences derived this way, it is part of the language
- Never wastes time exploring ungrammatical trees!

Data-driven/bottom-up:

- Start with the sentence.
- For each **substring**, find a non-terminal which covers it.
- Never generates trees that are inconsistent with the sentence.

Wait a minute

Not everybody in this room knows something about
ALGORITHM

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An algorithm is a **precise**, **unambiguous**, **mechanical**, **correct** specification of **how to solve a class of problems**.

宫保鸡丁

原料，鸡腿三只



宫保鸡丁

鸡腿肉切成大拇指甲大小的丁



宫保鸡丁

加入豌豆淀粉、酱油、料酒，拌匀后腌制十分钟入味



宫保鸡丁

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兑碗芡：调味碗中加入豌豆淀粉、盐、胡椒粉、白糖、醋、酱油



宫保鸡丁

锅内下少许油六成油温加入干辣椒和花椒粒炆锅，再加入姜、葱、蒜炆出香味（葱只加一半）



宫保鸡丁

再下入码味以后的鸡丁下锅，大火翻炒至鸡丁成熟，倒入兑好的料汁并继续快速炒匀



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加入剩下的葱，最后加入油酥花生米炒匀起锅装盘（花生米一定是最后加）



宫保鸡丁

SUCCESS



宫保鸡丁

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- 2 加入豌豆淀粉、酱油、料酒，拌匀后腌制十分钟入味
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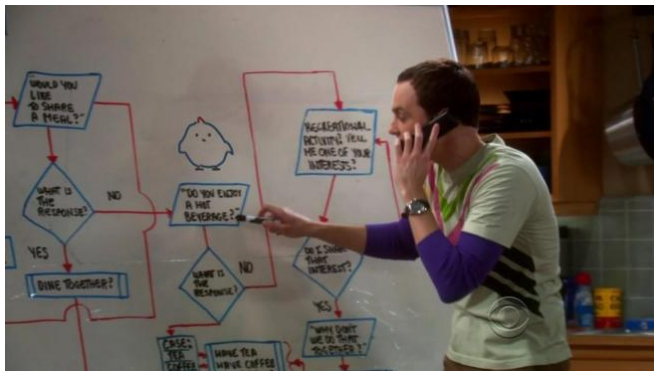
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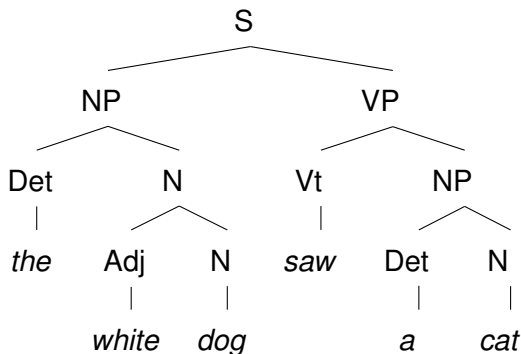
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Algorithm



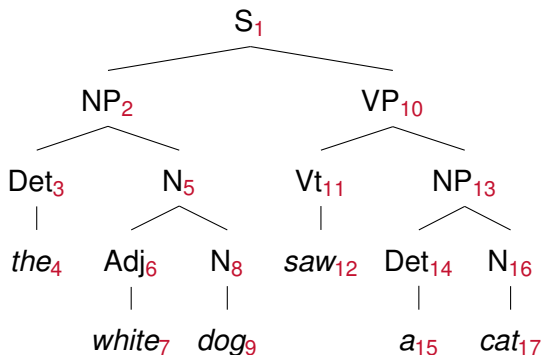
An example (top-down)

$S \rightarrow NP VP$ $VP \rightarrow Vt NP$ $NP \rightarrow Det N$ $N \rightarrow Adj N$
 $Vt \rightarrow \text{*saw*}$ $Det \rightarrow \text{*the*}$ $Det \rightarrow \text{*a*}$ $N \rightarrow \text{*cat*}$
 $N \rightarrow \text{*dog*}$ $Adj \rightarrow \text{*white*}$



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Left-to-right, left-most derivation

An example (cont)

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cat VP	white dog saw the cat	fail with <i>cat</i>
dog VP	white dog saw the cat	fail with <i>dog</i>
Adj N VP	white dog saw the cat	PREDICT Adj
white N VP	white dog saw the cat	SCAN <i>white</i>
N VP	dog saw the cat	PREDICT N
dog VP	dog saw the cat	SCAN <i>dog</i>
VP	saw the cat	PREDICT VP
	...	
∅	∅	SUCCESS!

An example (cont)

Goal	Input	Action
S	the white dog saw the cat	PREDICT S
NP VP	the white dog saw the cat	PREDICT NP
Det N VP	the white dog saw the cat	PREDICT Det
the N VP	the white dog saw the cat	SCAN <i>the</i>
N VP	white dog saw the cat	PREDICT N
cat VP	white dog saw the cat	fail with <i>cat</i>
dog VP	white dog saw the cat	fail with <i>dog</i>
Adj N VP	white dog saw the cat	PREDICT Adj
white N VP	white dog saw the cat	SCAN <i>white</i>
N VP	dog saw the cat	PREDICT N
dog VP	dog saw the cat	SCAN <i>dog</i>
VP	saw the cat	PREDICT VP
	...	
∅	∅	SUCCESS!

An example (cont)

Goal	Input	Action
S	the white dog saw the cat	PREDICT S
NP VP	the white dog saw the cat	PREDICT NP
Det N VP	the white dog saw the cat	PREDICT Det
the N VP	the white dog saw the cat	SCAN <i>the</i>
N VP	white dog saw the cat	PREDICT N
cat VP	white dog saw the cat	fail with <i>cat</i>
dog VP	white dog saw the cat	fail with <i>dog</i>
Adj N VP	white dog saw the cat	PREDICT Adj
white N VP	white dog saw the cat	SCAN <i>white</i>
N VP	dog saw the cat	PREDICT N
dog VP	dog saw the cat	SCAN <i>dog</i>
VP	saw the cat	PREDICT VP
	...	
∅	∅	SUCCESS!

An example (cont)

Goal	Input	Action
S	the white dog saw the cat	PREDICT S
NP VP	the white dog saw the cat	PREDICT NP
Det N VP	the white dog saw the cat	PREDICT Det
the N VP	the white dog saw the cat	SCAN <i>the</i>
N VP	white dog saw the cat	PREDICT N
cat VP	white dog saw the cat	fail with <i>cat</i>
dog VP	white dog saw the cat	fail with <i>dog</i>
Adj N VP	white dog saw the cat	PREDICT Adj
white N VP	white dog saw the cat	SCAN <i>white</i>
N VP	dog saw the cat	PREDICT N
dog VP	dog saw the cat	SCAN <i>dog</i>
VP	saw the cat	PREDICT VP
	...	
∅	∅	SUCCESS!

An example (cont)

Goal	Input	Action
S	the white dog saw the cat	PREDICT S
NP VP	the white dog saw the cat	PREDICT NP
Det N VP	the white dog saw the cat	PREDICT Det
the N VP	the white dog saw the cat	SCAN <i>the</i>
N VP	white dog saw the cat	PREDICT N
cat VP	white dog saw the cat	fail with <i>cat</i>
dog VP	white dog saw the cat	fail with <i>dog</i>
Adj N VP	white dog saw the cat	PREDICT Adj
white N VP	white dog saw the cat	SCAN <i>white</i>
N VP	dog saw the cat	PREDICT N
dog VP	dog saw the cat	SCAN <i>dog</i>
VP	saw the cat	PREDICT VP
	...	
∅	∅	SUCCESS!

An example (cont)

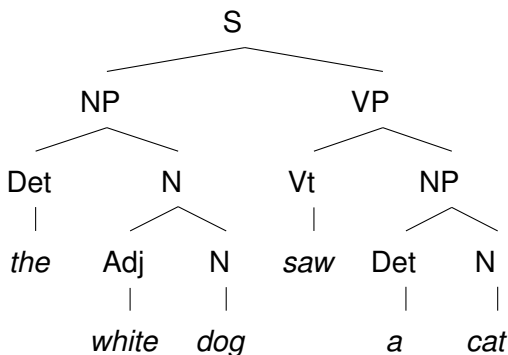
Goal	Input	Action
S	the white dog saw the cat	PREDICT S
NP VP	the white dog saw the cat	PREDICT NP
Det N VP	the white dog saw the cat	PREDICT Det
the N VP	the white dog saw the cat	SCAN <i>the</i>
N VP	white dog saw the cat	PREDICT N
cat VP	white dog saw the cat	fail with <i>cat</i>
dog VP	white dog saw the cat	fail with <i>dog</i>
Adj N VP	white dog saw the cat	PREDICT Adj
white N VP	white dog saw the cat	SCAN <i>white</i>
N VP	dog saw the cat	PREDICT N
dog VP	dog saw the cat	SCAN <i>dog</i>
VP	saw the cat	PREDICT VP
	...	
∅	∅	SUCCESS!

An example (cont)

Goal	Input	Action
S	the white dog saw the cat	PREDICT S
NP VP	the white dog saw the cat	PREDICT NP
Det N VP	the white dog saw the cat	PREDICT Det
the N VP	the white dog saw the cat	SCAN <i>the</i>
N VP	white dog saw the cat	PREDICT N
cat VP	white dog saw the cat	fail with <i>cat</i>
dog VP	white dog saw the cat	fail with <i>dog</i>
Adj N VP	white dog saw the cat	PREDICT Adj
white N VP	white dog saw the cat	SCAN <i>white</i>
N VP	dog saw the cat	PREDICT N
dog VP	dog saw the cat	SCAN <i>dog</i>
VP	saw the cat	PREDICT VP
	...	
∅	∅	SUCCESS!

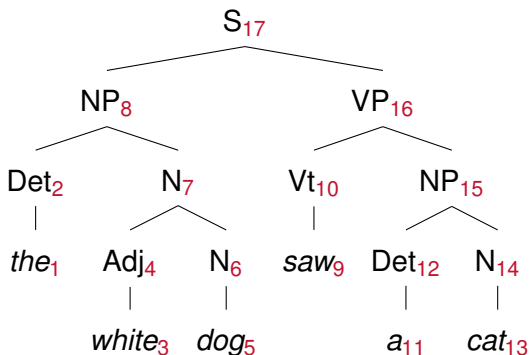
An example (bottom-up)

$S \rightarrow NP VP$ $VP \rightarrow Vt NP$ $NP \rightarrow Det N$ $N \rightarrow Adj N$
 $Vt \rightarrow saw$ $Det \rightarrow the$ $Det \rightarrow a$ $N \rightarrow cat$
 $N \rightarrow dog$ $Adj \rightarrow white$



An example (bottom-up)

$S \rightarrow NP VP$ $VP \rightarrow Vt NP$ $NP \rightarrow Det N$ $N \rightarrow Adj N$
 $Vt \rightarrow \text{saw}$ $Det \rightarrow \text{the}$ $Det \rightarrow \text{a}$ $N \rightarrow \text{cat}$
 $N \rightarrow \text{dog}$ $Adj \rightarrow \text{white}$



Left-to-right, right-most derivation

An example (cont)

Analysis	Input	Action
\emptyset	the white dog saw the cat	SHIFT <i>the</i>
the	white dog saw the cat	REDUCE <i>the</i> to Det
Det	white dog saw the cat	SHIFT <i>white</i>
Det white	dog saw the cat	REDUCE <i>white</i> to Adj
Det Adj	dog saw the cat	SHIFT <i>dog</i>
Det Adj dog	saw the cat	REDUCE <i>dog</i> to N
Det Adj N	saw the cat	REDUCE Adj N to N
Det N	saw the cat	REDUCE Det N to NP
NP	saw the cat	SHIFT <i>saw</i>
NP saw	the cat	REDUCE <i>saw</i> to Vt
NP Vt	the cat	SHIFT <i>the</i>
NP Vt the	cat	REDUCE <i>the</i> to Det
	...	
S	\langle empty \rangle	SUCCESS!

An example (cont)

Analysis	Input	Action
∅	the white dog saw the cat	SHIFT <i>the</i>
the	white dog saw the cat	REDUCE <i>the</i> to Det
Det	white dog saw the cat	SHIFT <i>white</i>
Det white	dog saw the cat	REDUCE <i>white</i> to Adj
Det Adj	dog saw the cat	SHIFT <i>dog</i>
Det Adj dog	saw the cat	REDUCE <i>dog</i> to N
Det Adj N	saw the cat	REDUCE Adj N to N
Det N	saw the cat	REDUCE Det N to NP
NP	saw the cat	SHIFT <i>saw</i>
NP saw	the cat	REDUCE <i>saw</i> to Vt
NP Vt	the cat	SHIFT <i>the</i>
NP Vt the	cat	REDUCE <i>the</i> to Det
	...	
S	⟨empty⟩	SUCCESS!

An example (cont)

Analysis	Input	Action
\emptyset	the white dog saw the cat	SHIFT <i>the</i>
the	white dog saw the cat	REDUCE <i>the</i> to Det
Det	white dog saw the cat	SHIFT <i>white</i>
Det white	dog saw the cat	REDUCE <i>white</i> to Adj
Det Adj	dog saw the cat	SHIFT <i>dog</i>
Det Adj dog	saw the cat	REDUCE <i>dog</i> to N
Det Adj N	saw the cat	REDUCE Adj N to N
Det N	saw the cat	REDUCE Det N to NP
NP	saw the cat	SHIFT <i>saw</i>
NP saw	the cat	REDUCE <i>saw</i> to Vt
NP Vt	the cat	SHIFT <i>the</i>
NP Vt the	cat	REDUCE <i>the</i> to Det
	...	
S	\langle empty \rangle	SUCCESS!

An example (cont)

Analysis	Input	Action
\emptyset	the white dog saw the cat	SHIFT <i>the</i>
the	white dog saw the cat	REDUCE <i>the</i> to Det
Det	white dog saw the cat	SHIFT <i>white</i>
Det white	dog saw the cat	REDUCE <i>white</i> to Adj
Det Adj	dog saw the cat	SHIFT <i>dog</i>
Det Adj dog	saw the cat	REDUCE <i>dog</i> to N
Det Adj N	saw the cat	REDUCE Adj N to N
Det N	saw the cat	REDUCE Det N to NP
NP	saw the cat	SHIFT <i>saw</i>
NP saw	the cat	REDUCE <i>saw</i> to Vt
NP Vt	the cat	SHIFT <i>the</i>
NP Vt the	cat	REDUCE <i>the</i> to Det
	...	
S	\langle empty \rangle	SUCCESS!

An example (cont)

Analysis	Input	Action
\emptyset	the white dog saw the cat	SHIFT <i>the</i>
the	white dog saw the cat	REDUCE <i>the</i> to Det
Det	white dog saw the cat	SHIFT <i>white</i>
Det white	dog saw the cat	REDUCE <i>white</i> to Adj
Det Adj	dog saw the cat	SHIFT <i>dog</i>
Det Adj dog	saw the cat	REDUCE <i>dog</i> to N
Det Adj N	saw the cat	REDUCE Adj N to N
Det N	saw the cat	REDUCE Det N to NP
NP	saw the cat	SHIFT <i>saw</i>
NP saw	the cat	REDUCE <i>saw</i> to Vt
NP Vt	the cat	SHIFT <i>the</i>
NP Vt the	cat	REDUCE <i>the</i> to Det
	...	
S	\langle empty \rangle	SUCCESS!

An example (cont)

Analysis	Input	Action
\emptyset	the white dog saw the cat	SHIFT <i>the</i>
the	white dog saw the cat	REDUCE <i>the</i> to Det
Det	white dog saw the cat	SHIFT <i>white</i>
Det <i>white</i>	dog saw the cat	REDUCE <i>white</i> to Adj
Det Adj	dog saw the cat	SHIFT <i>dog</i>
Det Adj dog	saw the cat	REDUCE <i>dog</i> to N
Det Adj N	saw the cat	REDUCE Adj N to N
Det N	saw the cat	REDUCE Det N to NP
NP	saw the cat	SHIFT <i>saw</i>
NP saw	the cat	REDUCE <i>saw</i> to Vt
NP Vt	the cat	SHIFT <i>the</i>
NP Vt the	cat	REDUCE <i>the</i> to Det
	...	
S	\langle empty \rangle	SUCCESS!

An example (cont)

Analysis	Input	Action
\emptyset	the white dog saw the cat	SHIFT <i>the</i>
the	white dog saw the cat	REDUCE <i>the</i> to Det
Det	white dog saw the cat	SHIFT <i>white</i>
Det white	dog saw the cat	REDUCE <i>white</i> to Adj
Det Adj	dog saw the cat	SHIFT <i>dog</i>
Det Adj dog	saw the cat	REDUCE <i>dog</i> to N
Det Adj N	saw the cat	REDUCE Adj N to N
Det N	saw the cat	REDUCE Det N to NP
NP	saw the cat	SHIFT <i>saw</i>
NP saw	the cat	REDUCE <i>saw</i> to Vt
NP Vt	the cat	SHIFT <i>the</i>
NP Vt the	cat	REDUCE <i>the</i> to Det
	...	
S	\langle empty \rangle	SUCCESS!

An example (cont)

Analysis	Input	Action
\emptyset	the white dog saw the cat	SHIFT <i>the</i>
the	white dog saw the cat	REDUCE <i>the</i> to Det
Det	white dog saw the cat	SHIFT <i>white</i>
Det white	dog saw the cat	REDUCE <i>white</i> to Adj
Det Adj	dog saw the cat	SHIFT <i>dog</i>
Det Adj dog	saw the cat	REDUCE <i>dog</i> to N
Det Adj N	saw the cat	REDUCE Adj N to N
Det N	saw the cat	REDUCE Det N to NP
NP	saw the cat	SHIFT <i>saw</i>
NP saw	the cat	REDUCE <i>saw</i> to Vt
NP Vt	the cat	SHIFT <i>the</i>
NP Vt the	cat	REDUCE <i>the</i> to Det
	...	
S	\langle empty \rangle	SUCCESS!

An example (cont)

Analysis	Input	Action
\emptyset	the white dog saw the cat	SHIFT <i>the</i>
the	white dog saw the cat	REDUCE <i>the</i> to Det
Det	white dog saw the cat	SHIFT <i>white</i>
Det white	dog saw the cat	REDUCE <i>white</i> to Adj
Det Adj	dog saw the cat	SHIFT <i>dog</i>
Det Adj dog	saw the cat	REDUCE <i>dog</i> to N
Det Adj N	saw the cat	REDUCE Adj N to N
Det N	saw the cat	REDUCE Det N to NP
NP	saw the cat	SHIFT <i>saw</i>
NP saw	the cat	REDUCE <i>saw</i> to Vt
NP Vt	the cat	SHIFT <i>the</i>
NP Vt the	cat	REDUCE <i>the</i> to Det
	...	
S	\langle empty \rangle	SUCCESS!

An example (cont)

Analysis	Input	Action
\emptyset	the white dog saw the cat	SHIFT <i>the</i>
the	white dog saw the cat	REDUCE <i>the</i> to Det
Det	white dog saw the cat	SHIFT <i>white</i>
Det white	dog saw the cat	REDUCE <i>white</i> to Adj
Det Adj	dog saw the cat	SHIFT <i>dog</i>
Det Adj dog	saw the cat	REDUCE <i>dog</i> to N
Det Adj N	saw the cat	REDUCE Adj N to N
Det N	saw the cat	REDUCE Det N to NP
NP	saw the cat	SHIFT <i>saw</i>
NP saw	the cat	REDUCE <i>saw</i> to Vt
NP Vt	the cat	SHIFT <i>the</i>
NP Vt the	cat	REDUCE <i>the</i> to Det
	...	
S	\langle empty \rangle	SUCCESS!

An example (cont)

Analysis	Input	Action
\emptyset	the white dog saw the cat	SHIFT <i>the</i>
the	white dog saw the cat	REDUCE <i>the</i> to Det
Det	white dog saw the cat	SHIFT <i>white</i>
Det white	dog saw the cat	REDUCE <i>white</i> to Adj
Det Adj	dog saw the cat	SHIFT <i>dog</i>
Det Adj dog	saw the cat	REDUCE <i>dog</i> to N
Det Adj N	saw the cat	REDUCE Adj N to N
Det N	saw the cat	REDUCE Det N to NP
NP	saw the cat	SHIFT <i>saw</i>
NP saw	the cat	REDUCE <i>saw</i> to Vt
NP Vt	the cat	SHIFT <i>the</i>
NP Vt the	cat	REDUCE <i>the</i> to Det
	...	
S	\langle empty \rangle	SUCCESS!

An example (cont)

Analysis	Input	Action
\emptyset	the white dog saw the cat	SHIFT <i>the</i>
the	white dog saw the cat	REDUCE <i>the</i> to Det
Det	white dog saw the cat	SHIFT <i>white</i>
Det white	dog saw the cat	REDUCE <i>white</i> to Adj
Det Adj	dog saw the cat	SHIFT <i>dog</i>
Det Adj dog	saw the cat	REDUCE <i>dog</i> to N
Det Adj N	saw the cat	REDUCE Adj N to N
Det N	saw the cat	REDUCE Det N to NP
NP	saw the cat	SHIFT <i>saw</i>
NP saw	the cat	REDUCE <i>saw</i> to Vt
NP Vt	the cat	SHIFT <i>the</i>
NP Vt the	cat	REDUCE <i>the</i> to Det
	...	
S	\langle empty \rangle	SUCCESS!

An example (cont)

Analysis	Input	Action
\emptyset	the white dog saw the cat	SHIFT <i>the</i>
the	white dog saw the cat	REDUCE <i>the</i> to Det
Det	white dog saw the cat	SHIFT <i>white</i>
Det white	dog saw the cat	REDUCE <i>white</i> to Adj
Det Adj	dog saw the cat	SHIFT <i>dog</i>
Det Adj dog	saw the cat	REDUCE <i>dog</i> to N
Det Adj N	saw the cat	REDUCE Adj N to N
Det N	saw the cat	REDUCE Det N to NP
NP	saw the cat	SHIFT <i>saw</i>
NP saw	the cat	REDUCE <i>saw</i> to Vt
NP Vt	the cat	SHIFT <i>the</i>
NP Vt the	cat	REDUCE <i>the</i> to Det
	...	
S	\langle empty \rangle	SUCCESS!

An example (cont)

Analysis	Input	Action
\emptyset	the white dog saw the cat	SHIFT <i>the</i>
the	white dog saw the cat	REDUCE <i>the</i> to Det
Det	white dog saw the cat	SHIFT <i>white</i>
Det white	dog saw the cat	REDUCE <i>white</i> to Adj
Det Adj	dog saw the cat	SHIFT <i>dog</i>
Det Adj dog	saw the cat	REDUCE <i>dog</i> to N
Det Adj N	saw the cat	REDUCE Adj N to N
Det N	saw the cat	REDUCE Det N to NP
NP	saw the cat	SHIFT <i>saw</i>
NP saw	the cat	REDUCE <i>saw</i> to Vt
NP Vt	the cat	SHIFT <i>the</i>
NP Vt the	cat	REDUCE <i>the</i> to Det
	...	
S	\langle empty \rangle	SUCCESS!

An example

Analysis	Input	Action
\emptyset	the white dog saw the cat	SHIFT <i>the</i>
the	white dog saw the cat	REDUCE <i>the</i> to Det
Det	white dog saw the cat	SHIFT <i>white</i>
Det white	dog saw the cat	REDUCE <i>white</i> to Adj
Det Adj	dog saw the cat	SHIFT <i>dog</i>
Det Adj dog	saw the cat	REDUCE <i>dog</i> to N
Det Adj N	saw the cat	REDUCE Adj N to N
Det N	saw the cat	REDUCE Det N to NP

...

An example

Analysis	Input	Action
\emptyset	the white dog saw the cat	SHIFT <i>the</i>
the	white dog saw the cat	REDUCE <i>the</i> to Det
Det	white dog saw the cat	SHIFT <i>white</i>
Det white	dog saw the cat	REDUCE <i>white</i> to Adj
Det Adj	dog saw the cat	SHIFT <i>dog</i>
Det Adj dog	saw the cat	REDUCE <i>dog</i> to N
Det Adj N	saw the cat	REDUCE Adj N to N
Det N	saw the cat	REDUCE Det N to NP

...

- What are “鸡腿”, “葱”, “酱油”, “白糖”?

An example

Analysis	Input	Action
\emptyset	the white dog saw the cat	SHIFT <i>the</i>
the	white dog saw the cat	REDUCE <i>the</i> to Det
Det	white dog saw the cat	SHIFT <i>white</i>
Det white	dog saw the cat	REDUCE <i>white</i> to Adj
Det Adj	dog saw the cat	SHIFT <i>dog</i>
Det Adj dog	saw the cat	REDUCE <i>dog</i> to N
Det Adj N	saw the cat	REDUCE Adj N to N
Det N	saw the cat	REDUCE Det N to NP

...

- What are “鸡腿”, “葱”, “酱油”, “白糖”?
- What are “锅”, “盘”, “碗”?

An example

Analysis	Input	Action
\emptyset	the white dog saw the cat	SHIFT <i>the</i>
the	white dog saw the cat	REDUCE <i>the</i> to Det
Det	white dog saw the cat	SHIFT <i>white</i>
Det white	dog saw the cat	REDUCE <i>white</i> to Adj
Det Adj	dog saw the cat	SHIFT <i>dog</i>
Det Adj dog	saw the cat	REDUCE <i>dog</i> to N
Det Adj N	saw the cat	REDUCE Adj N to N
Det N	saw the cat	REDUCE Det N to NP

...

- What are “鸡腿”, “葱”, “酱油”, “白糖”?
- What are “锅”, “盘”, “碗”?
- What are “切”, “炒”, “兑”, “装”?

How about ambiguous sentences

Example

- (1) a. Penny [_{VP} oil-wrestle [_{NP} [_{NP} an orangutan] [_{PP} in a bikini]]].
b. Penny [_{VP} [_{VP} oil-wrestle [_{NP} an orangutan]] [_{PP} in a bikini]].

Grammar rules:

- $VP \rightarrow VP PP$
- $NP \rightarrow NP PP$

The object NP (*an orangutan*) and the PP (*in a bikini*) has the same analysis.

Solution: Dynamic programming!

Use a parse table

A representation of the string showing positions and word indices:

$\cdot_0 w_1 \cdot_1 w_2 \cdot_2 w_3 \cdot_3 w_4 \cdot_4 w_5 \cdot_5 w_6 \cdot_6$

Coverage represented in the chart:

TO:

	1	2	3	4	5	6
FROM: 0	0-1	0-2	0-3	0-4	0-5	0-6
1		1-2	1-3	1-4	1-5	1-6
2			2-3	2-4	2-5	2-6
3				3-4	3-5	3-6
4					4-5	4-6
5						5-6

An example

\cdot_0 Penny \cdot_1 oil-wrestles \cdot_2 an \cdot_3 orangutan \cdot_4 in \cdot_5 a \cdot_6 bikini \cdot_7

	1	2	3	4	5	6	7
0	P	P oil-wrestles	P..an	P..orangutan	P..in	P..a	P..bikini
1		oil-wrestles	oil..an	oil..orangutan	oil..in	oil..a	oil..bikini
2			an	an orangutan	an..in	an..a	an..bikini
3				orangutan	orangutan in	orangutan..a	orangutan..bikini
4					in	in a	in..bikini
5						a	a bikini
6							bikini

An example

\cdot_0 Penny \cdot_1 oil-wrestles \cdot_2 an \cdot_3 orangutan \cdot_4 in \cdot_5 a \cdot_6 bikini \cdot_7

	1	2	3	4	5	6	7
0	P	P oil-wrestles	P..an	P..orangutan	P..in	P..a	P..bikini
1		oil-wrestles	oil..an	oil..orangutan	oil..in	oil..a	oil..bikini
2			an	an orangutan	an..in	an..a	an..bikini
3				orangutan	orangutan in	orangutan..a	orangutan..bikini
4					in	in a	in..bikini
5						a	a bikini
6							bikini

新式“锅”，“盘”，“碗”？

The CKY algorithm

Who are CKY?

- Kasami
- Younger
- Cocke

Algorithm schema

- Store partial parse in a **chart**.
 - In each cell, store the possible phrase types.
- Visit each cell exactly once
 - in a topological order

An example

Sentence

\cdot_0 Penny \cdot_1 oil-wrestles \cdot_2 an \cdot_3 orangutan \cdot_4 in \cdot_5 a \cdot_6 bikini \cdot_7

Chart

	1	2	3	4	5	6	7
0	NP			S			S
1		V		VP			VP
2			Det	NP			NP
3				N			
4					P		PP
5						Det	NP
6							N

An example

Sentence

·₀ Penny ·₁ oil-wrestles ·₂ an ·₃ orangutan ·₄ in ·₅ a ·₆ bikini ·₇

Chart

	1	2	3	4	5	6	7
0	NP			S			S
1		V		VP			VP
2			Det	NP			NP
3				N			
4					P		PP
5						Det	NP
6							N

An example

Sentence

·₀ Penny ·₁ oil-wrestles ·₂ an ·₃ orangutan ·₄ in ·₅ a ·₆ bikini ·₇

Chart

	1	2	3	4	5	6	7
0	NP			S			S
1		V		VP			VP
2			Det	NP			NP
3				N			
4					P		PP
5						Det	NP
6							N

An example

Sentence

\cdot_0 Penny \cdot_1 oil-wrestles \cdot_2 an \cdot_3 orangutan \cdot_4 in \cdot_5 a \cdot_6 bikini \cdot_7

Chart

	1	2	3	4	5	6	7
0	NP			S			S
1		V		VP			VP
2			Det	NP			NP
3				N			
4					P		PP
5						Det	NP
6							N

An example

Sentence

·₀ Penny ·₁ oil-wrestles ·₂ an ·₃ orangutan ·₄ in ·₅ a ·₆ bikini ·₇

Chart

	1	2	3	4	5	6	7
0	NP			S			S
1		V		VP			VP
2			Det	NP			NP
3				N			
4					P		PP
5						Det	NP
6							N

An example

Sentence

·₀ Penny ·₁ oil-wrestles ·₂ an ·₃ orangutan ·₄ in ·₅ a ·₆ bikini ·₇

Chart

	1	2	3	4	5	6	7
0	NP			S			S
1		V		VP			VP
2			Det	NP			NP
3				N			
4					P		PP
5						Det	NP
6							N

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Parsing as Deduction 拉拉扯扯

Parsing as deduction

Representing various parsing algorithms using **a formal logic framework as deduction systems**.

- **Items (formulas)** describe the grammatical status of strings, and **inference rules** produce new items from already generated items.

Advantages:

- Concentration on parsing strategy
- Reflecting the structure of parsers in a clear and concise manner.
- Facilitation of correctness

Soundness: If the algorithm yields `true` for w , then $w \in L(G)$.

Completeness: If $w \in L(G)$, then the algorithm yields `true` for w .

Recap: Language and Inference

Items

$\text{All}(X, Y)$ (where $X, Y \in N$)

Inference rules

$$\frac{\text{All}(X, Y) \quad \text{All}(Y, Z)}{\text{All}(X, Z)} \text{Trans}$$

$$\frac{}{\text{All}(X, X)} \text{Id}$$

Proofs

$$\frac{\frac{\text{All}(A, B) \quad \text{All}(B, C)}{\text{All}(A, C)} (\text{Trans}) \quad \text{All}(C, D)}{\text{All}(A, D)} (\text{Trans})$$

Parsing deduction system

A parsing deduction system can be specified as

- A set of items
- A subclass of items, the goal items
- A set of inference rules
- A set of axioms

The general form of a rule of inference is

$$\frac{A_1, \dots, A_k}{B} \text{ (Side conditions on } A_1, \dots, A_k, B)$$

The antecedents A_1, \dots, A_k and the consequent B of the rule are items. Axioms can be represented as inference rules with empty set of antecedents.

Example: CKY

Let $G = (V, T, P, S)$ be a CFG in Chomsky Normal Form, $s = w_1 \dots w_n$ a string in T^* . Compute sets $T_{i,j}$ ($0 \leq i < j \leq n$) of nonterminals such that $A \in V$ belongs to $T_{i,j}$ iff $A \xrightarrow{*} w_{i+1} \dots w_j$.

How

- For $0 \leq i < j \leq n$ set $T_{ij} = \emptyset$.
- For $0 \leq i < n$ add nonterminal A to $T_{i,i+1}$ iff $A \rightarrow w_i$.
- For $0 \leq i < j - 1 < n$ add nonterminal A to $T_{i,j}$ iff there is a rule $A \rightarrow BC$ and $k \in \{i + 1, \dots, j - 1\}$ with $B \in T_{i,k}$ and $C \in T_{k,j}$.
- $w \in L(G)$ iff $S \in T_{1,n}$

Example: CKY

Let $G = (V, T, P, S)$ be a CFG in Chomsky Normal Form, $s = w_1 \dots w_n$ a string in T^* . Compute sets $T_{i,j}$ ($0 \leq i < j \leq n$) of nonterminals such that $A \in V$ belongs to $T_{i,j}$ iff $A \xrightarrow{*} w_{i+1} \dots w_j$.

Deduction

- Item: $[A, i, j]$
- Axioms:

$$\frac{}{[A, i-1, i]} (A \rightarrow w_i)$$

- Inference Rules:

$$\frac{[B, i, k] \quad [C, k, j]}{[A, i, j]} (A \rightarrow BC)$$

- Goals: $[S, 0, n]$

Correctness

Deduction

- Item: $[A, i, j]$
- Axioms:

$$\frac{}{[A, i, j]} (A \rightarrow w_i)$$

- Inference Rules:

$$\frac{[B, i, k] \quad [C, k, j]}{[A, i, j]} (A \rightarrow BC)$$

- Goals: $[S, 1, n]$

Soundness:

If the algorithm yields `true` for w , then $w \in L(G)$.

Completeness:

If $w \in L(G)$, then the algorithm yields `true` for w .

- Chapter 3 & 4, Grune, D. and Jacobs, C.J.H. (2008). Parsing Techniques: A Practical Guide. A Practical Guide
- * Shieber, S. M., Schabes, Y., and Pereira, F. C. N. (1995). Principles and implementation of deductive parsing. Journal of Logic Programming.