

Часть 4. Автоматический синтаксический анализ

Алгоритмы реализации синтаксического анализа в терминах контекстно-свободной грамматики (КСГ)

Алгоритмы реализации анализа в терминах КСГ (Context-Free Grammar, CFG)

- ПЛАН

- Алгоритмы:

- Метод рекурсивного спуска (top-down parsing)
 - Восходящий анализ (bottom-up parsing)
 - Алгоритм Кока-Янгера-Касами (CKY Parsing)
 - Алгоритм Эрли (Earley parser)

- Методы улучшения качества:

- Вероятностные контекстно-свободные грамматики (PCFG)
 - Лексикализованные контекстно-свободные грамматики

- “Борьба” с разрывными составляющими

Алгоритмы реализации анализа в терминах КСГ (Context-Free Grammar, CFG)

- Алгоритмы:
 - Метод рекурсивного спуска (top-down parsing)
 - Восходящий анализ (bottom-up parsing)
 - Алгоритм Кока-Янгера-Касами (CKY Parsing)
 - Алгоритм Эрли (Earley parser)

Алгоритмы реализации анализа в терминах КСГ (Context-Free Grammar, CFG)

- Что значит провести синтаксический анализ в терминах НС?
 - ✓ Поставить в соответствие предложению (цепочке терминальных символов) систему вложенных составляющих (расставить скобки)

Дано:

КС-грамматика, предложение

Найти:

множество правил из КС-грамматики, которые это предложение порождают

Алгоритмы синтаксического анализа в терминах CFG

- Нам дано 2 набора данных:
 - Цепочка терминальных символов
 - Начальный символ

Пример

S → NP VP

S → Aux NP VP

S → VP

NP → Pronoun

NP → Proper-Noun

NP → Det Nominal

Nominal → Noun

Nominal → Nominal Noun

Nominal → Nominal PP

VP → Verb

VP → Verb NP

VP → Verb NP PP

VP → Verb PP

VP → VP PP

PP → Preposition NP

Det → that | this | a

Noun → book | flight | meal | money

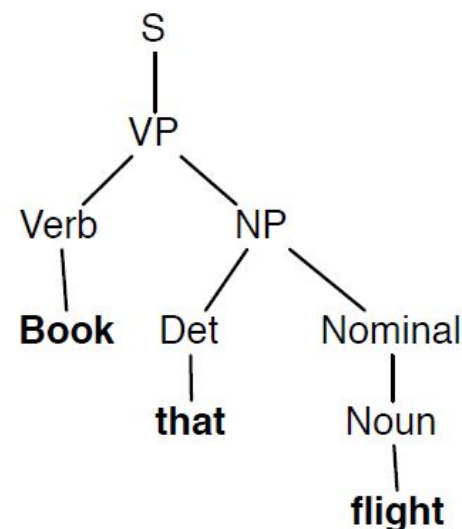
Verb → book | include | prefer

Pronoun → I | she | me

Proper-Noun → Houston | TWA

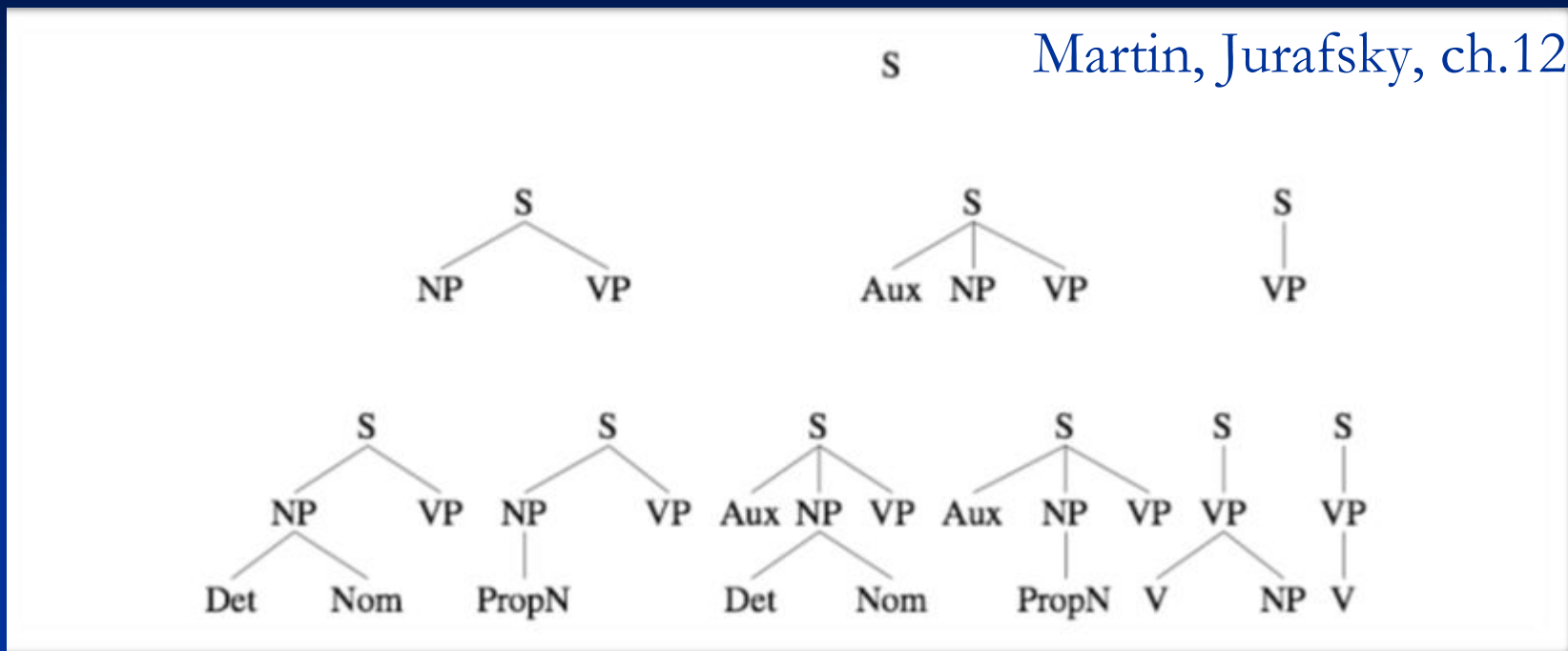
Aux → does

Preposition → from | to | on | near | through



Martin, Jurafsky, ch.12

Метод рекурсивного спуска



- “Разворачивать” узлы начинаем слева
- Разворачиваем каждое дерево пока не доберемся до частей речи
- отклоняем деревья, листья которых не совпадают с цепочкой частей речи анализируемого предложения

Восходящий анализ

Book that fly

Noun	Det	Noun	Verb	Det	Noun
Book	that	flight	Book	that	flight

Nominal		Nominal			Nominal
Noun	Det	Noun	Verb	Det	Noun
Book	that	flight	Book	that	flight

	NP			NP	
	/			/	
Nominal		Nominal	VP	Nominal	Nominal
Noun	Det	Noun	Verb	Det	Noun
Book	that	flight	Book	that	flight

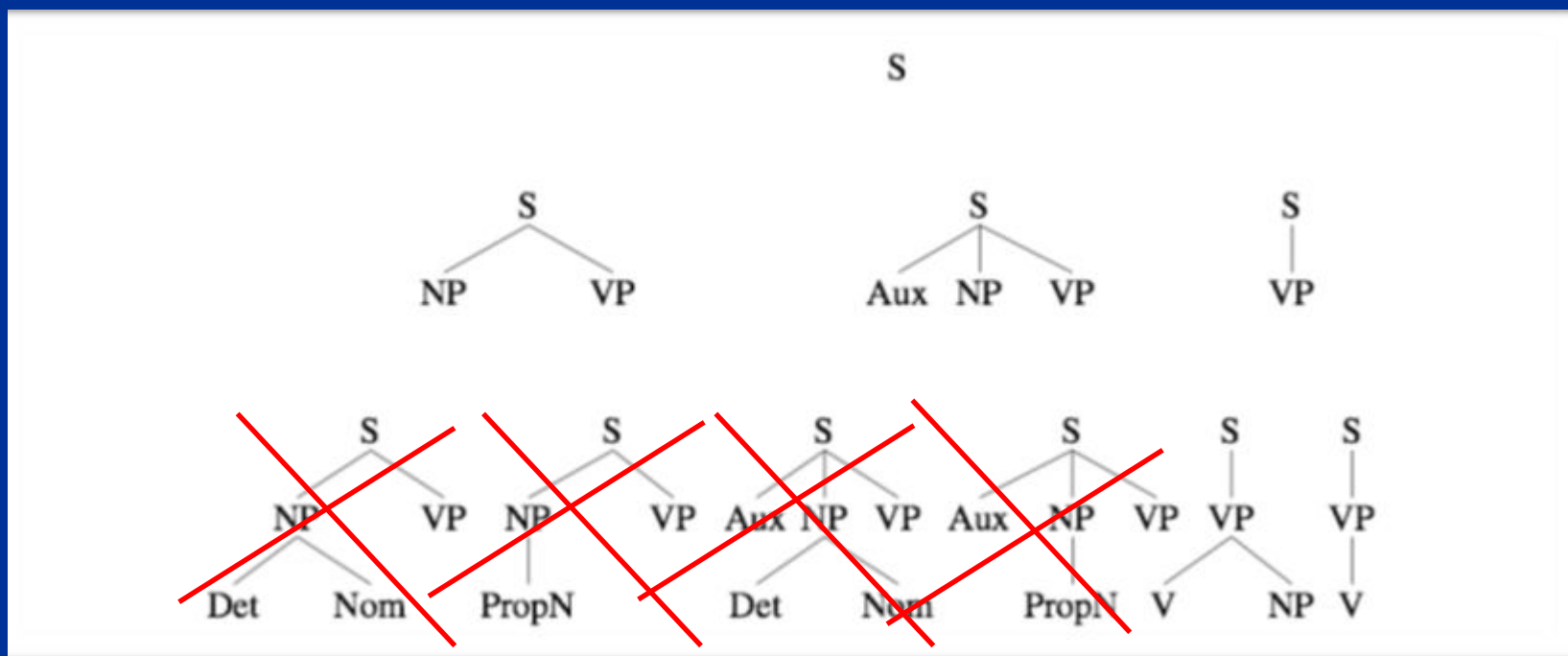
			VP		
			/		
VP	NP	Nominal		NP	Nominal
	/			/	
Verb	Det	Noun	Verb	Det	Noun
Book	that	flight	Book	that	flight

Martin, Jurafsky,
ch.12

Стандартный алгоритм «сверху вниз».

Фильтр «Снизу вверх»

- Проверка крайнего левого элемента в деривации



Book that fly

Алгоритм СУК

Алгоритм Кока-Янгера-Касами (СУК Parsing)

- Нормальная форма Хомского
- Допускаются только правила вида
- $X \rightarrow BC, X \rightarrow w$
- Петя подарил Маше книгу
- $VP \rightarrow V NP NP$

Типы «нарушающих» правил:

(1) $X \rightarrow Bw$, (2) $X \rightarrow B$, (3) $X \rightarrow ABC$

(1) $X \rightarrow Bw$: $INF-VP \rightarrow to VP \rightarrow INF-VP \rightarrow TO VP$; $TO \rightarrow to$

(2) $X \rightarrow B$: $NP \rightarrow Nominal, Nominal \rightarrow N \rightarrow NP \rightarrow N$

(3) $X \rightarrow ABC$: $NP \rightarrow D N NP \rightarrow NP \rightarrow D Nominal$;
 $Nominal \rightarrow N NP$

Алгоритм СУК

Исходная грамматика

$S \rightarrow NP VP$
 $S \rightarrow Aux NP VP$
 $S \rightarrow VP$

$NP \rightarrow Pronoun$
 $NP \rightarrow Proper-Noun$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow Noun$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$
 $VP \rightarrow Verb$
 $VP \rightarrow Verb NP$
 $VP \rightarrow Verb NP PP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$
 $PP \rightarrow Preposition NP$

Алгоритм СҮК

Приведение к нормальной форме Хомского

$S \rightarrow NP VP$	$S \rightarrow NP VP$
$S \rightarrow Aux NP VP$	$S \rightarrow XI VP$
	$XI \rightarrow Aux NP$
$S \rightarrow VP$	$S \rightarrow book \mid include \mid prefer$
	$S \rightarrow Verb NP$
	$S \rightarrow X2 PP$
	$S \rightarrow Verb PP$
	$S \rightarrow VP PP$
$NP \rightarrow Pronoun$	$NP \rightarrow I \mid she \mid me$
$NP \rightarrow Proper-Noun$	$NP \rightarrow TWA \mid Houston$
$NP \rightarrow Det Nominal$	$NP \rightarrow Det Nominal$
$Nominal \rightarrow Noun$	$Nominal \rightarrow book \mid flight \mid meal \mid money$
$Nominal \rightarrow Nominal Noun$	$Nominal \rightarrow Nominal Noun$
$Nominal \rightarrow Nominal PP$	$Nominal \rightarrow Nominal PP$
$VP \rightarrow Verb$	$VP \rightarrow book \mid include \mid prefer$
$VP \rightarrow Verb NP$	$VP \rightarrow Verb NP$
$VP \rightarrow Verb NP PP$	$VP \rightarrow X2 PP$
	$X2 \rightarrow Verb NP$
$VP \rightarrow Verb PP$	$VP \rightarrow Verb PP$
$VP \rightarrow VP PP$	$VP \rightarrow VP PP$
$PP \rightarrow Preposition NP$	$PP \rightarrow Preposition NP$

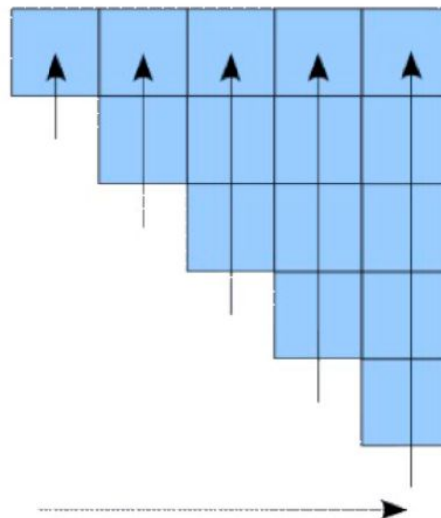
Figure 12.8 \mathcal{L}_1 Grammar and its conversion to CNF.

Алгоритм СУК

Распознавание

Book the flight through Houston

S ; VP, Nominal, Verb,Noun [0,1]		S, VP, X2		S1, VP1, S2, VP2, S3 [0,5]
	[0,2]	[0,3]	[0,4]	[0,5]
	Det	NP		NP
	[1,2]	[1,3]	[1,4]	[1,5]
		Nominal, Noun		Nominal
		[2,3]	[2,4]	[2,5]
			Prep	PP
			[3,4]	[3,5]
				NP, Proper- Noun [0,1]



$S \rightarrow NP VP$

$S \rightarrow XI VP$

$XI \rightarrow Aux NP$

$S \rightarrow book \mid include \mid prefer$

$S \rightarrow Verb NP$

$S \rightarrow X2 PP$

$S \rightarrow Verb PP$

$S \rightarrow VP PP$

$NP \rightarrow I \mid she \mid me$

$NP \rightarrow TWA \mid Houston$

$NP \rightarrow Det Nominal$

$Nominal \rightarrow book \mid flight \mid meal \mid money$

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book \mid include \mid prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
 $S \rightarrow VP PP$
 $NP \rightarrow I \mid she \mid me$
 $NP \rightarrow TWA \mid Houston$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow book \mid flight \mid meal \mid money$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$
 $VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$
 $PP \rightarrow Preposition NP$

Det \rightarrow that I this I a
 Noun \rightarrow book I flight I meal I money
 Verb \rightarrow book I include I prefer
 Pronoun \rightarrow I I she I me
 Proper-Noun \rightarrow Houston I TWA
 Aux \rightarrow does
 Preposition \rightarrow from I to I on I near I through

Алгоритм СҮК

Синтаксический разбор

$S \rightarrow \bar{N}P VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
 $S \rightarrow VP PP$
 $NP \rightarrow I \mid she \mid me$
 $NP \rightarrow TWA \mid Houston$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow book \mid flight \mid meal \mid money$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$
 $VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$
 $PP \rightarrow Preposition NP$

	Book	the	flight	through	Houston
[0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
	[1,2]	[1,3]	[1,4]	[1,5]	
		[2,3]	[2,4]	[2,5]	
			[3,4]	[3,5]	PP
					[0,1]

$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
 $S \rightarrow VP PP$
 $NP \rightarrow I \mid she \mid me$
 $NP \rightarrow TWA \mid Houston$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow book \mid flight \mid meal \mid money$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$
 $VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$
 $PP \rightarrow Preposition NP$

Det \rightarrow that I this I a
 Noun \rightarrow book I flight I meal I money
 Verb \rightarrow book I include I prefer
 Pronoun \rightarrow I I she I me
 Proper-Noun \rightarrow Houston I TWA
 Aux \rightarrow does
 Preposition \rightarrow from I to I on I near I through

Алгоритм СУК

Синтаксический разбор

$S \rightarrow \bar{N}P VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
 $S \rightarrow VP PP$
 $NP \rightarrow I \mid she \mid me$
 $NP \rightarrow TWA \mid Houston$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow book \mid flight \mid meal \mid money$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$
 $VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$
 $PP \rightarrow Preposition NP$

	Book	the	flight	through	Houston
S, VP, Verb, Nominal, Noun [0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
	[1,2]	[1,3]	[1,4]	[1,5]	
		[2,3]	[2,4]	[2,5]	
			[3,4]	[3,5]	PP
					[0,1]

Det → that | this | a
 Noun → book | flight | meal | money
 Verb → book | include | prefer
 Pronoun → I | she | me
 Proper-Noun → Houston | TWA
 Aux → does
 Preposition → from | to | on | near | through

$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
 $S \rightarrow VP PP$
 $NP \rightarrow I \mid she \mid me$
 $NP \rightarrow TWA \mid Houston$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow book \mid flight \mid meal \mid money$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$
 $VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$
 $PP \rightarrow Preposition NP$

Det \rightarrow that I this I a
 Noun \rightarrow book I flight I meal I money
 Verb \rightarrow book I include I prefer
 Pronoun \rightarrow I I she I me
 Proper-Noun \rightarrow Houston I TWA
 Aux \rightarrow does
 Preposition \rightarrow from I to I on I near I through

Алгоритм СҮК

Синтаксический разбор

$S \rightarrow \bar{NP} VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
 $S \rightarrow VP PP$
 $NP \rightarrow I \mid she \mid me$
 $NP \rightarrow TWA \mid Houston$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow book \mid flight \mid meal \mid money$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$
 $VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$
 $PP \rightarrow Preposition NP$

	Book	the	flight	through	Houston
S, VP, Verb, Nominal, Noun [0,1]	no [0,2]	[0,3]	[0,4]	[0,5]	
	Det [1,2]	[1,3]	[1,4]	[1,5]	
		[2,3]	[2,4]	[2,5]	
			[3,4]	[3,5]	PP
					[0,1]

Det → that | this | a
 Noun → book | flight | meal | money
 Verb → book | include | prefer
 Pronoun → I | she | me
 Proper-Noun → Houston | TWA
 Aux → does
 Preposition → from | to | on | near | through

$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
 $S \rightarrow VP PP$
 $NP \rightarrow I \mid she \mid me$
 $NP \rightarrow TWA \mid Houston$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow book \mid flight \mid meal \mid money$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$
 $VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$
 $PP \rightarrow Preposition NP$

Det \rightarrow that I this I a
 Noun \rightarrow book I flight I meal I money
 Verb \rightarrow book I include I prefer
 Pronoun \rightarrow I I she I me
 Proper-Noun \rightarrow Houston I TWA
 Aux \rightarrow does
 Preposition \rightarrow from I to I on I near I through

Алгоритм СҮК

Синтаксический разбор

$S \rightarrow \bar{N}P VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
 $S \rightarrow VP PP$
 $NP \rightarrow I \mid she \mid me$
 $NP \rightarrow TWA \mid Houston$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow book \mid flight \mid meal \mid money$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$
 $VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$
 $PP \rightarrow Preposition NP$

	Book	the	flight	through	Houston
S, VP, Verb, Nominal, Noun [0,1]	[0,2]	[0,3]	[0,4]	[0,5]	
	Det [1,2]	[1,3]	[1,4]	[1,5]	
		Nominal, Noun [2,3]	[2,4]	[2,5]	
			[3,4]	PP [3,5]	
					[0,1]

Det → that | this | a
 Noun → book | flight | meal | money
 Verb → book | include | prefer
 Pronoun → I | she | me
 Proper-Noun → Houston | TWA
 Aux → does
 Preposition → from | to | on | near | through

$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
 $S \rightarrow VP PP$
 $NP \rightarrow I \mid she \mid me$
 $NP \rightarrow TWA \mid Houston$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow book \mid flight \mid meal \mid money$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$
 $VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$
 $PP \rightarrow Preposition NP$

Det \rightarrow that I this I a
 Noun \rightarrow book I flight I meal I money
 Verb \rightarrow book I include I prefer
 Pronoun \rightarrow I I she I me
 Proper-Noun \rightarrow Houston I TWA
 Aux \rightarrow does
 Preposition \rightarrow from I to I on I near I through

Алгоритм СУК

Синтаксический разбор

$S \rightarrow \bar{NP} VP$

$S \rightarrow X1 VP$

$X1 \rightarrow Aux NP$

$S \rightarrow book \mid include \mid prefer$

$S \rightarrow Verb NP$

$S \rightarrow X2 PP$

$S \rightarrow Verb PP$

$S \rightarrow VP PP$

$NP \rightarrow I \mid she \mid me$

$NP \rightarrow TWA \mid Houston$

$NP \rightarrow Det Nominal$

$Nominal \rightarrow book \mid flight \mid meal \mid money$

$Nominal \rightarrow Nominal Noun$

$Nominal \rightarrow Nominal PP$

$VP \rightarrow book \mid include \mid prefer$

$VP \rightarrow Verb NP$

$VP \rightarrow X2 PP$

$X2 \rightarrow Verb NP$

$VP \rightarrow Verb PP$

$VP \rightarrow VP PP$

$PP \rightarrow Preposition NP$

< the flight through Houston

verb,				
	[0,2]	[0,3]	[0,4]	[0,5]
Det ←		NP		
	[1,2]	[1,3]	[1,4]	[1,5]
		Nominal, Noun		
		[2,3]	[2,4]	[2,5]
				PP
			[3,4]	[3,5]
				[0,1]

Det → that I this I a

Noun → book I flight I meal I money

Verb → book I include I prefer

Pronoun → I I she I me

Proper-Noun → Houston I TWA

Aux → does

Preposition → from I to I on I near I through

$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
 $S \rightarrow VP PP$
 $NP \rightarrow I \mid she \mid me$
 $NP \rightarrow TWA \mid Houston$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow book \mid flight \mid meal \mid money$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$
 $VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$
 $PP \rightarrow Preposition NP$

Det \rightarrow that I this I a
 Noun \rightarrow book I flight I meal I money
 Verb \rightarrow book I include I prefer
 Pronoun \rightarrow I I she I me
 Proper-Noun \rightarrow Houston I TWA
 Aux \rightarrow does
 Preposition \rightarrow from I to I on I near I through

Алгоритм СУК

Синтаксический разбор

$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow VP$
 $S \rightarrow X2 PP$
 $NP \rightarrow Pronoun$
 $NP \rightarrow Proper-Noun$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow Noun$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$
 $VP \rightarrow Verb$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$
 $PP \rightarrow Preposition NP$

Book	the	flight	through	Houston
S, VP, Verb Nominal, Noun [0,1]	[0,2]	[0,3]	[0,4]	[0,5]
	Det [1,2]	NP [1,3]	[1,4]	[1,5]
		Nominal, Noun [2,3]	[2,4]	[2,5]
			[3,4]	PP [3,5]
				[0,1]

$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
 $S \rightarrow VP PP$
 $NP \rightarrow I \mid she \mid me$
 $NP \rightarrow TWA \mid Houston$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow book \mid flight \mid meal \mid money$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$
 $VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$
 $PP \rightarrow Preposition NP$

Det \rightarrow that I this I a
 Noun \rightarrow book I flight I meal I money
 Verb \rightarrow book I include I prefer
 Pronoun \rightarrow I I she I me
 Proper-Noun \rightarrow Houston I TWA
 Aux \rightarrow does
 Preposition \rightarrow from I to I on I near I through

Алгоритм СУК

Синтаксический разбор

$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow VP$
 $S \rightarrow X2 PP$
 $NP \rightarrow Pronoun$
 $NP \rightarrow Proper-Noun$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow Noun$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$
 $VP \rightarrow Verb$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$
 $PP \rightarrow Preposition NP$

Book	the	flight	through	Houston
$S, VP, Verb,$ $Nominal,$ $Noun$ $[0,1]$	no	no		
	Det	NP		
	$[1,2]$	$[1,3]$	$[1,4]$	$[1,5]$
		Nominal, Noun		
		$[2,3]$	$[2,4]$	$[2,5]$
			Prep	PP
			$[3,4]$	$[3,5]$
				$[0,1]$

$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
 $S \rightarrow VP PP$
 $NP \rightarrow I \mid she \mid me$
 $NP \rightarrow TWA \mid Houston$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow book \mid flight \mid meal \mid money$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$
 $VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$
 $PP \rightarrow Preposition NP$

Det \rightarrow that I this I a
 Noun \rightarrow book I flight I meal I money
 Verb \rightarrow book I include I prefer
 Pronoun \rightarrow I I she I me
 Proper-Noun \rightarrow Houston I TWA
 Aux \rightarrow does
 Preposition \rightarrow from I to I on I near I through

Алгоритм СҮК

Синтаксический разбор

$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow VP$
 $S \rightarrow X2 PP$
 $NP \rightarrow Pronoun$
 $NP \rightarrow Proper-Noun$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow Noun$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$
 $VP \rightarrow Verb$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$
 $PP \rightarrow Preposition NP$

Book	the	flight	through	Houston
S, VP, Verb, Nominal, Noun [0,1]	[0,2]	S, VP, X2 [0,3]	[0,4]	[0,5]
	Det [1,2]	NP [1,3]	[1,4]	[1,5]
		Nominal, Noun [2,3]	[2,4]	[2,5]
			Prep [3,4]	PP [3,5]
				NP, Proper- Noun [0,1]

$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
 $S \rightarrow VP PP$
 $NP \rightarrow I \mid she \mid me$
 $NP \rightarrow TWA \mid Houston$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow book \mid flight \mid meal \mid money$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$
 $VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$
 $PP \rightarrow Preposition NP$

Det \rightarrow that I this I a
 Noun \rightarrow book I flight I meal I money
 Verb \rightarrow book I include I prefer
 Pronoun \rightarrow I I she I me
 Proper-Noun \rightarrow Houston I TWA
 Aux \rightarrow does
 Preposition \rightarrow from I to I on I near I through

Алгоритм СҮК

Синтаксический разбор

$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow VP$
 $S \rightarrow X2 PP$
 $NP \rightarrow Pronoun$
 $NP \rightarrow Proper-Noun$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow Noun$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$
 $VP \rightarrow Verb$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$
 $PP \rightarrow Preposition NP$

Book	the	flight	through	Houston
S, VP, Verb, Nominal, Noun [0,1]	[0,2]	S, VP, X2 [0,3]	[0,4]	[0,5]
	Det [1,2]	NP [1,3]	[1,4]	[1,5]
		Nominal; Noun [2,3]	[2,4]	Nominal [2,5]
			Prep [3,4]	PP [3,5]
				NP, Proper- Noun [0,1]

$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
 $S \rightarrow VP PP$
 $NP \rightarrow I \mid she \mid me$
 $NP \rightarrow TWA \mid Houston$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow book \mid flight \mid meal \mid money$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$
 $VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$
 $PP \rightarrow Preposition NP$

Det \rightarrow that I this I a
Noun \rightarrow book I flight I meal I money
Verb \rightarrow book I include I prefer
Pronoun \rightarrow I I she I me
Proper-Noun \rightarrow Houston I TWA
Aux \rightarrow does
Preposition \rightarrow from I to I on I near I through

Алгоритм СУК

Синтаксический разбор

$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow VP$
 $S \rightarrow X2 PP$
 $NP \rightarrow Pronoun$
 $NP \rightarrow Proper-Noun$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow Noun$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$
 $VP \rightarrow Verb$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$
 $PP \rightarrow Preposition NP$

Book the flight through Houston				
S, VP, Verb, Nominal, Noun [0,1]		S, VP, X2 [0,3]		
	Det [1,2]	NP [1,3]		NP [1,5]
		Nominal, Noun [2,3]		Nominal [2,5]
			Prep [3,4]	PP [3,5]
				NP, Proper- Noun [0,1]

$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
 $S \rightarrow VP PP$
 $NP \rightarrow I \mid she \mid me$
 $NP \rightarrow TWA \mid Houston$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow book \mid flight \mid meal \mid money$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$
 $VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$
 $PP \rightarrow Preposition NP$

Det \rightarrow that I this I a
 Noun \rightarrow book I flight I meal I money
 Verb \rightarrow book I include I prefer
 Pronoun \rightarrow I I she I me
 Proper-Noun \rightarrow Houston I TWA
 Aux \rightarrow does
 Preposition \rightarrow from I to I on I near I through

Алгоритм СУК

Синтаксический разбор

$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow VP$
 $S \rightarrow X2 PP$
 $NP \rightarrow Pronoun$
 $NP \rightarrow Proper-Noun$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow Noun$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$
 $VP \rightarrow Verb$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$
 $PP \rightarrow Preposition NP$

Book	the	flight	through	Houston
S, VP, Verb, Nominal, Noun [0,1]	[0,2]	S, VP, X2 [0,3]	[0,4]	S1, VP1, S2, VP2, S3 [0,5]
	Det [1,2]	NP [1,3]	[1,4]	NP [1,5]
		Nominal; Noun [2,3]	[2,4]	Nominal [2,5]
			Prep [3,4]	PP [3,5]
				NP, Proper- Noun [0,1]

$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
 $S \rightarrow VP PP$
 $NP \rightarrow I \mid she \mid me$
 $NP \rightarrow TWA \mid Houston$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow book \mid flight \mid meal \mid money$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$
 $VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$
 $PP \rightarrow Preposition NP$

Det \rightarrow that I this I a
 Noun \rightarrow book I flight I meal I money
 Verb \rightarrow book I include I prefer
 Pronoun \rightarrow I I she I me
 Proper-Noun \rightarrow Houston I TWA
 Aux \rightarrow does
 Preposition \rightarrow from I to I on I near I through

Алгоритм СУК

Синтаксический разбор

$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow VP$
 $S \rightarrow X2 PP$
 $NP \rightarrow Pronoun$
 $NP \rightarrow Proper-Noun$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow Noun$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$
 $VP \rightarrow Verb$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$
 $PP \rightarrow Preposition NP$

Book the flight through Houston				
S, VP, Verb, Nominal, Noun [0,1]	[0,2]	S, VP, X2 [0,3]	[0,4]	S1, VP1, \$2, VP2, \$3 [0,5]
	Det [1,2]	NP [1,3]	[1,4]	NP [1,5]
		Nominal; Noun [2,3]	[2,4]	Nominal [2,5]
			Prep [3,4]	PP [3,5]
				NP, Proper- Noun [0,1]

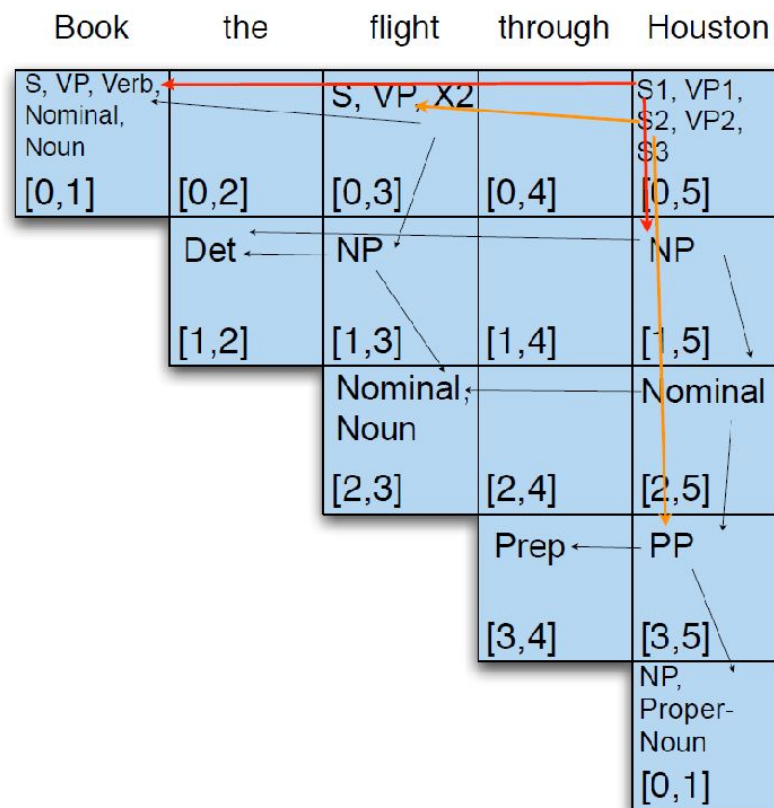
$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
 $S \rightarrow VP PP$
 $NP \rightarrow I \mid she \mid me$
 $NP \rightarrow TWA \mid Houston$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow book \mid flight \mid meal \mid money$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$
 $VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$
 $PP \rightarrow Preposition NP$

Det \rightarrow that I this I a
 Noun \rightarrow book I flight I meal I money
 Verb \rightarrow book I include I prefer
 Pronoun \rightarrow I I she I me
 Proper-Noun \rightarrow Houston I TWA
 Aux \rightarrow does
 Preposition \rightarrow from I to I on I near I through

Алгоритм СҮК

Синтаксический разбор

$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow VP$
 $S \rightarrow X2 PP$
 $NP \rightarrow Pronoun$
 $NP \rightarrow Proper-Noun$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow Noun$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$
 $VP \rightarrow Verb$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$
 $PP \rightarrow Preposition NP$



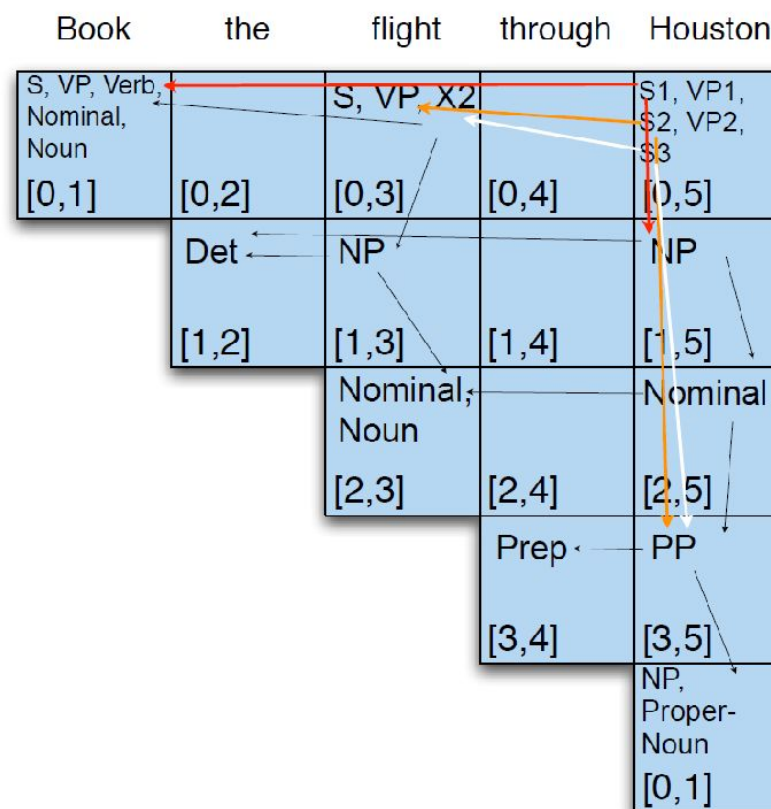
$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
 $S \rightarrow VP PP$
 $NP \rightarrow I \mid she \mid me$
 $NP \rightarrow TWA \mid Houston$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow book \mid flight \mid meal \mid money$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$
 $VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$
 $PP \rightarrow Preposition NP$

Det \rightarrow that I this I a
 Noun \rightarrow book I flight I meal I money
 Verb \rightarrow book I include I prefer
 Pronoun \rightarrow I I she I me
 Proper-Noun \rightarrow Houston I TWA
 Aux \rightarrow does
 Preposition \rightarrow from I to I on I near I through

Алгоритм СУК

Синтаксический разбор

$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow VP$
 $S \rightarrow X2 PP$
 $NP \rightarrow Pronoun$
 $NP \rightarrow Proper-Noun$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow Noun$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$
 $VP \rightarrow Verb$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$
 $PP \rightarrow Preposition NP$



$S \rightarrow NP VP$
 $S \rightarrow X1 VP$
 $X1 \rightarrow Aux NP$
 $S \rightarrow book \mid include \mid prefer$
 $S \rightarrow Verb NP$
 $S \rightarrow X2 PP$
 $S \rightarrow Verb PP$
 $S \rightarrow VP PP$
 $NP \rightarrow I \mid she \mid me$
 $NP \rightarrow TWA \mid Houston$
 $NP \rightarrow Det Nominal$
 $Nominal \rightarrow book \mid flight \mid meal \mid money$
 $Nominal \rightarrow Nominal Noun$
 $Nominal \rightarrow Nominal PP$
 $VP \rightarrow book \mid include \mid prefer$
 $VP \rightarrow Verb NP$
 $VP \rightarrow X2 PP$
 $X2 \rightarrow Verb NP$
 $VP \rightarrow Verb PP$
 $VP \rightarrow VP PP$
 $PP \rightarrow Preposition NP$

Det \rightarrow that I this I a
 Noun \rightarrow book I flight I meal I money
 Verb \rightarrow book I include I prefer
 Pronoun \rightarrow I I she I me
 Proper-Noun \rightarrow Houston I TWA
 Aux \rightarrow does
 Preposition \rightarrow from I to I on I near I through

Алгоритм СУК

- Шаг 0. Преобразовать грамматику к нормальной форме
- Алгоритм (динамическое программирование)

```
function CKY-PARSE(words, grammar) returns table
  for  $j \leftarrow$  from 1 to LENGTH(words) do
     $table[j-1, j] \leftarrow \{A \mid A \rightarrow words[j] \in grammar\}$ 
    for  $i \leftarrow$  from  $j-2$  downto 0 do
      for  $k \leftarrow i+1$  to  $j-1$  do
         $table[i, j] \leftarrow table[i, j] \cup$ 
           $\{A \mid A \rightarrow BC \in grammar,$ 
             $B \in table[i, k],$ 
             $C \in table[k, j]\}$ 
```