Parsing: PCFGs

Ling 571 Deep Processing Techniques for NLP January 21, 2015

Roadmap

- Motivation: Ambiguity
- Approach:
 - Probabilistic Context-free Grammars (PCFGs)
 - Definition
 - Disambiguation
 - Parsing
 - Evaluation
 - Enhancements

Probabilistic Parsing

- Provides strategy for solving disambiguation problem
 - Compute the probability of all analyses
 - Select the most probable

Probabilistic Parsing

- Provides strategy for solving disambiguation problem
 - Compute the probability of all analyses
 - Select the most probable
- Employed in language modeling for speech recognition
 - N-gram grammars predict words, constrain search
 - Also, constrain generation, translation

- Probabilistic Context-free Grammars
 - Augmentation of CFGs
 - N a set of **non-terminal symbols** (or **variables**)
 - Σ a set of **terminal symbols** (disjoint from *N*)
 - *R* a set of **rules** or productions, each of the form $A \rightarrow \beta$ [*p*], where *A* is a non-terminal,

 β is a string of symbols from the infinite set of strings $(\Sigma \cup N)*$, and *p* is a number between 0 and 1 expressing $P(\beta | A)$

S a designated start symbol

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- Augment each production with probability that LHS will be expanded as RHS
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 - Sum over all possible expansions is 1

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 - Sum over all possible expansions is 1

$$\sum_{\beta} P(A \to \beta) = 1$$

- A PCFG is consistent if sum of probabilities of all sentences in language is 1.
 - Recursive rules often yield inconsistent grammars

Example PCFG

Grammar		Lexicon
$S \rightarrow NP VP$	[.80]	$Det \rightarrow that [.10] \mid a [.30] \mid the [.60]$
$S \rightarrow Aux NP VP$	[.15]	Noun \rightarrow book [.10] flight [.30]
$S \rightarrow VP$	[.05]	<i>meal</i> [.15] <i>money</i> [.05]
$NP \rightarrow Pronoun$	[.35]	<i>flights</i> [.40] <i>dinner</i> [.10]
$NP \rightarrow Proper-Noun$	[.30]	$Verb \rightarrow book [.30] \mid include [.30]$
$NP \rightarrow Det Nominal$	[.20]	<i>prefer</i> ;[.40]
$NP \rightarrow Nominal$	[.15]	$Pronoun \rightarrow I[.40] \mid she [.05]$
$Nominal \rightarrow Noun$	[.75]	<i>me</i> [.15] <i>you</i> [.40]
$Nominal \rightarrow Nominal Noun$	[.20]	<i>Proper-Noun</i> \rightarrow <i>Houston</i> [.60]
Nominal \rightarrow Nominal PP	[.05]	NWA [.40]
$VP \rightarrow Verb$	[.35]	$Aux \rightarrow does [.60] \mid can [40]$
$VP \rightarrow Verb NP$	[.20]	Preposition \rightarrow from [.30] to [.30]
$VP \rightarrow Verb NP PP$	[.10]	<i>on</i> [.20] <i>near</i> [.15]
$VP \rightarrow Verb PP$	[.15]	through [.05]
$VP \rightarrow Verb NP NP$	[.05]	
$VP \rightarrow VP PP$	[.15]	
$PP \rightarrow Preposition NP$	[1.0]	

Disambiguation

- A PCFG assigns probability to each parse tree T for input S.
 - Probability of T: product of all rules to derive T

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$$P(T,S) = \prod_{i=1}^{n} P(RHS_i \mid LHS_i)$$

Disambiguation

- A PCFG assigns probability to each parse tree T for input S.
 - Probability of T: product of all rules to derive T

$$P(T,S) = \prod_{i=1}^{n} P(RHS_i \mid LHS_i)$$
$$P(T,S) = P(T)P(S \mid T) = P(T)$$

S VP Verb NP	<		Verb			P
the Nomina I Noun I Noun I Noun I Noun	ninal I Noun flight		 Book	Det the	Nominal Nom Noun Not dinner flig	inal un <i>ht</i>
Ru	iles	Р		Rı	ıles	Р
$S \longrightarrow$	VP	.05	S	\rightarrow	VP	.05
$VP \rightarrow$	Verb NP	.20	VP	\rightarrow	Verb NP NP	.10
$NP \rightarrow$	Det Nominal	.20	NP	\rightarrow	Det Nominal	.20
Nominal \rightarrow	Nominal Noun	.20	NP	\rightarrow	Nominal	.15
Nominal \rightarrow	Noun	.75	Nominal	\rightarrow	Noun	.75
			Nominal	\rightarrow	Noun	.75
Verb \rightarrow	book	.30	Verb	\rightarrow	book	.30
Det \rightarrow	the	.60	Det	\rightarrow	the	.60
Noun \rightarrow	dinner	.10	Noun	\rightarrow	dinner	.10
Noun \rightarrow	flights	.40	Noun	\rightarrow	flights	.40

P(T,S)=0.05

S VP 		S VP
Verb NP		Verb NP NP
Book Det Nominal		
the Nominal Noun		Book Det Nominal Nominal
		the Noun Noun
Noun flight		dinner di Le
dinner		ainner flight
Rules	Р	Rules P
$S \rightarrow VP$.05	S \rightarrow VP .05
$VP \longrightarrow Verb NP$.20	VP \rightarrow Verb NP NP .10
NP \rightarrow Det Nominal	.20	NP \rightarrow Det Nominal .20
Nominal \rightarrow Nominal Noun	.20	NP \rightarrow Nominal .15
Nominal \rightarrow Noun	.75	Nominal \rightarrow Noun .75
		Nominal \rightarrow Noun .75
Verb \rightarrow book	.30	Verb \rightarrow book .30
Det \rightarrow the	.60	Det \rightarrow the .60
Noun \rightarrow dinner	.10	Noun \rightarrow dinner .10
Noun \rightarrow flights	.40	Noun \rightarrow flights .40

P(T,S)=0.05*0.2

S VP Verb NP	<		Verb			P
the Nomina I Noun I Noun I Noun I Noun	ninal I Noun flight		 Book	Det the	Nominal Nom Noun Not dinner flig	inal un <i>ht</i>
Ru	iles	Р		Rı	ıles	Р
$S \longrightarrow$	VP	.05	S	\rightarrow	VP	.05
$VP \rightarrow$	Verb NP	.20	VP	\rightarrow	Verb NP NP	.10
$NP \rightarrow$	Det Nominal	.20	NP	\rightarrow	Det Nominal	.20
Nominal \rightarrow	Nominal Noun	.20	NP	\rightarrow	Nominal	.15
Nominal \rightarrow	Noun	.75	Nominal	\rightarrow	Noun	.75
			Nominal	\rightarrow	Noun	.75
Verb \rightarrow	book	.30	Verb	\rightarrow	book	.30
Det \rightarrow	the	.60	Det	\rightarrow	the	.60
Noun \rightarrow	dinner	.10	Noun	\rightarrow	dinner	.10
Noun \rightarrow	flights	.40	Noun	\rightarrow	flights	.40

P(T,S)=0.05*0.2*0.2

S VP		S VP
Verb NP		Verb NP NP
Book Det Nominal		
		Book Det Nominal Nominal
the Nominal Noun		the Noun N
Noun <i>flight</i>		ine Noun Noun
		dinner flight
 dinner		
Rules	Р	Rules P
$S \longrightarrow VP$.05	$S \rightarrow VP$.05
$VP \longrightarrow Verb NP$.20	VP \rightarrow Verb NP NP .10
NP \rightarrow Det Nominal	.20	NP \rightarrow Det Nominal .20
Nominal \rightarrow Nominal Noun	.20	NP \rightarrow Nominal .15
Nominal \rightarrow Noun	.75	Nominal \rightarrow Noun .75
		Nominal \rightarrow Noun .75
Verb \rightarrow book	.30	Verb \rightarrow book .30
Det \rightarrow the	.60	Det \rightarrow the .60
Noun \rightarrow dinner	.10	Noun \rightarrow dinner .10
Noun \rightarrow flights	.40	Noun \rightarrow flights .40

P(T,S)=0.05*0.2*0.2*0.2

		S VP
Verb NP		Verb NP NP
<i>the</i> Nominal Noun		Book Det Nominal Nominal the Noun Noun dinner flight
dinner		jugni
Rules	Р	Rules P
$S \longrightarrow VP$.05	$S \longrightarrow VP$.05
$VP \longrightarrow Verb NP$.20	VP \rightarrow Verb NP NP .10
NP \rightarrow Det Nominal	.20	NP \rightarrow Det Nominal .20
Nominal \rightarrow Nominal Noun	.20	NP \rightarrow Nominal .15
Nominal \rightarrow Noun	.75	Nominal \rightarrow Noun .75
		Nominal \rightarrow Noun .75
Verb \rightarrow book	.30	Verb \rightarrow book .30
Det \rightarrow the	.60	Det \rightarrow the .60
Noun \rightarrow dinner	.10	Noun \rightarrow dinner .10
Noun \rightarrow flights	.40	Noun \rightarrow flights .40

P(T,S)=0.05*0.2*0.2*0.2*0.75

S VP ~		S │ VP
Verb NP		
		Verb NP NP
Book Det Nominal		
the Nominal Noun		Book Det Nominal Nominal
ine Rominar Romi		the Noun Noun
Noun <i>flight</i>		
dinner		dinner flight
Delta		D 1 D
Rules	Р	Rules P
$S \rightarrow VP$.05	$S \rightarrow VP$.05
$VP \longrightarrow Verb NP$.20	VP \rightarrow Verb NP NP .10
NP \rightarrow Det Nominal	.20	NP \rightarrow Det Nominal .20
Nominal \rightarrow Nominal Nour	ı .20	NP \rightarrow Nominal .15
Nominal \rightarrow Noun	.75	Nominal \rightarrow Noun .75
		Nominal \rightarrow Noun .75
Verb \rightarrow book	.30	Verb \rightarrow book .30
Det \rightarrow the	.60	Det \rightarrow the .60
Noun \rightarrow dinner	.10	Noun \rightarrow dinner .10
Noun \rightarrow flights	.40	Noun \rightarrow flights .40

P(T,S)=0.05*0.2*0.2*0.2*0.75* 0.3

S VP				1	S VP	
Verb NP Book Det Nom	inal		Verb	1	NP NI	P
the Nominal Noun dinner	Noun flight		Book	Det the	Nominal Nom Noun Not dinner flig	inal un <i>ht</i>
Rul	les	Р		Rı	ıles	P
$\overline{S} \rightarrow V$	VP	.05	S	\rightarrow	VP	.05
$VP \longrightarrow V$	Verb NP	.20	VP	\rightarrow	Verb NP NP	.10
$NP \longrightarrow I$	Det Nominal	.20	NP	\rightarrow	Det Nominal	.20
Nominal \rightarrow N	Nominal Noun	.20	NP	\rightarrow	Nominal	.15
Nominal \rightarrow N	Noun	.75	Nominal	\rightarrow	Noun	.75
			Nominal	\rightarrow	Noun	.75
Verb \rightarrow b	book	.30	Verb	\rightarrow	book	.30
Det \rightarrow t	he	.60	Det	\rightarrow	the	.60
Noun \rightarrow d	linner	.10	Noun	\rightarrow	dinner	.10
Noun \rightarrow f	lights	.40	Noun	\rightarrow	flights	.40

P(T,S)=0.05*0.2*0.2*0.2*0.75* 0.3*0.6

				7	S VP	
Verb NP						
Rock	<		Verb	1	NP NI	P
BOOK Det Noi	ninal		Î.	~	\sim	
the Nomina	1 Noun		Book	Det	Nominal Nom	inal
				the	Noun Not	un
Noun	flight					
dinner					dinner flig	ht
Rı	iles	P		Rı	iles	P
	VD	05	S	K	VD	05
$3 \rightarrow $	VI Vorb ND	.05	S VD	\rightarrow	VI Vorb ND ND	10
$VP \rightarrow ND$	Det Neminel	.20	VF	\rightarrow	Det Neminal	.10
$NP \rightarrow N$	Det Nommar	.20	NP	\rightarrow		.20
Nominal \rightarrow	Nominal Noun	.20	NP	\rightarrow	Nominal	.15
Nominal \rightarrow	Noun	.75	Nominal	\rightarrow	Noun	.75
			Nominal	\rightarrow	Noun	.75
Verb \rightarrow	book	.30	Verb	\rightarrow	book	.30
Det \rightarrow	the	.60	Det	\rightarrow	the	.60
Noun \rightarrow	dinner	.10	Noun	\rightarrow	dinner	.10
Noun \rightarrow	flights	.40	Noun	\rightarrow	flights	.40

P(T,S)=0.05*0.2*0.2*0.2*0.75* 0.3*0.6*0.1

				,	S VP	
Verb NP Book Det Nom	inal		Verb	1	NP NI	P
the Nominal	Noun flight		Book	Det the	Nominal Nom Noun Nov dinner flig	inal un <i>ht</i>
Rul	es	Р		Rı	iles	P
$\overline{S} \rightarrow V$	VP	.05	S	\rightarrow	VP	.05
$VP \rightarrow V$	Verb NP	.20	VP	\rightarrow	Verb NP NP	.10
$NP \rightarrow I$	Det Nominal	.20	NP	\rightarrow	Det Nominal	.20
Nominal \rightarrow N	Nominal Noun	.20	NP	\rightarrow	Nominal	.15
Nominal \rightarrow N	Noun	.75	Nominal	\rightarrow	Noun	.75
			Nominal	\rightarrow	Noun	.75
Verb \rightarrow b	book	.30	Verb	\rightarrow	book	.30
Det \rightarrow the determinant of the	he	.60	Det	\rightarrow	the	.60
Noun \rightarrow d	linner	.10	Noun	\rightarrow	dinner	.10
Noun \rightarrow f	lights	.40	Noun	\rightarrow	flights	.40

S VP Verb NP				
Book Detail		Verb	NP N	P
Dook Det Nominal			ot Nominal N	
the Nominal Nour	1	BOOK D	et Nominal Non	linal
1 1		th	e Noun No	oun
Noun flight	f.		1.	
dinner			dinner flig	ght
Rules	Р	8	Rules	P
$S \rightarrow VP$.05	S -	\rightarrow VP	.05
$VP \rightarrow Verb N$	IP .20	VP -	\rightarrow Verb NP NP	.10
$NP \rightarrow Det Net$	ominal .20	NP -	\rightarrow Det Nominal	.20
Nominal \rightarrow Nomin	al Noun .20	NP -	\rightarrow Nominal	.15
Nominal \rightarrow Noun	.75	Nominal -	\rightarrow Noun	.75
		Nominal -	\rightarrow Noun	.75
Verb \rightarrow book	.30	Verb -	→ book	.30
Det \rightarrow the	.60	Det -	\rightarrow the	.60
Noun \rightarrow dinner	.10	Noun -	→ dinner	.10
Noun \rightarrow flights	.40	Noun -	\rightarrow flights	.40

P(T,S)=0.05

S VP		
Verb NP		
		Verb NP NP
Book Det Nominal		
the Naminal Nam		Book Det Nominal Nominal
ine Nommai Noun		the Noun Noun
Noun flight		
dinnar		dinner flight
anner		
Rules	Р	Rules P
$S \rightarrow VP$.05	$S \rightarrow VP$.05
$VP \longrightarrow Verb NP$.20	VP \rightarrow Verb NP NP .10
NP \rightarrow Det Nominal	.20	NP \rightarrow Det Nominal .20
Nominal \rightarrow Nominal Nour	n .20	NP \rightarrow Nominal .15
Nominal \rightarrow Noun	.75	Nominal \rightarrow Noun .75
		Nominal \rightarrow Noun .75
Verb \rightarrow book	.30	Verb \rightarrow book .30
Det \rightarrow the	.60	Det \rightarrow the .60
Noun \rightarrow dinner	.10	Noun \rightarrow dinner .10
Noun \rightarrow flights	.40	Noun \rightarrow flights .40

P(T,S)=0.05*0.1

			,	S ↓ VP	
Verb NP					
Book Det Nomina	1	Verb	1		P
	~	Book I	Det	Nominal Nom	inal
the Nominal No	oun	1	 he		
Noun <i>fli</i>	ght	1	ne		
dinner				dinner flig	ht
Rules	Р		Ru	ıles	P
$S \longrightarrow VP$.05	S	\rightarrow	VP	.05
$VP \rightarrow Vert$	DNP .20	VP	\rightarrow	Verb NP NP	.10
$NP \rightarrow Det$	Nominal .20	NP	\rightarrow	Det Nominal	.20
Nominal \rightarrow Nom	ninal Noun .20	NP	\rightarrow	Nominal	.15
Nominal \rightarrow Nou	in .75	Nominal	\rightarrow	Noun	.75
		Nominal	\rightarrow	Noun	.75
Verb \rightarrow boo	k .30	Verb	\rightarrow	book	.30
Det \rightarrow the	.60	Det	\rightarrow	the	.60
Noun \rightarrow dim	ner .10	Noun	\rightarrow	dinner	.10
Noun \rightarrow fligh	nts .40	Noun	\rightarrow	flights	.40

P(T,S)=0.05*0.1*0.15

	S VP						S VP	
	verb N	P						
E	Book Det	No	minal		Verb]	NP N	P
		/	\sim		Book	Det	Nominal Non	ninal
	the No	mina	al Noun			Ţ	I	
	N	 Joun	flight			the	Noun No	un
	1		jugni				dinner flig	pht
	di	nner	•				5.42	,
	3 .	R	ules	Р		Rı	ıles	Р
	S	\rightarrow	VP	.05	S	\rightarrow	VP	.05
	VP	\rightarrow	Verb NP	.20	VP	\rightarrow	Verb NP NP	.10
	NP	\rightarrow	Det Nominal	.20	NP	\rightarrow	Det Nominal	.20
	Nominal	\rightarrow	Nominal Noun	.20	NP	\rightarrow	Nominal	.15
	Nominal	\rightarrow	Noun	.75	Nominal	\rightarrow	Noun	.75
					Nominal	\rightarrow	Noun	.75
	Verb	\rightarrow	book	.30	Verb	\rightarrow	book	.30
	Det	\rightarrow	the	.60	Det	\rightarrow	the	.60
	Noun	\rightarrow	dinner	.10	Noun	\rightarrow	dinner	.10
	Noun	\rightarrow	flights	.40	Noun	\rightarrow	flights	.40

P(T,S)=0.05*0.1*0.15*0.75

S VP		S VP
Verb NP		Verb NP NP
Book Det Nominal		
the Nominal Noun		Book Det Nominal Nominal
		the Noun Noun
Noun <i>flight</i>		dinner
dinner		ainner flight
Rules	Р	Rules P
$S \longrightarrow VP$.05	S \rightarrow VP .05
$VP \longrightarrow Verb NP$.20	VP \rightarrow Verb NP NP .10
NP \rightarrow Det Nominal	.20	NP \rightarrow Det Nominal .20
Nominal \rightarrow Nominal Noun	.20	NP \rightarrow Nominal .15
Nominal \rightarrow Noun	.75	Nominal \rightarrow Noun .75
		Nominal \rightarrow Noun .75
Verb \rightarrow book	.30	Verb \rightarrow book .30
Det \rightarrow the	.60	Det \rightarrow the .60
Noun \rightarrow dinner	.10	Noun \rightarrow dinner .10
Noun \rightarrow flights	.40	Noun \rightarrow flights .40

P(T,S)=0.05*0.1*0.15*0.75*0.75*

Verb NP		Varb ND ND
Book Det Nominal		Vero NP NP
the Nominal Noun		Book Det Nominal Nominal
		the Noun Noun
Noun <i>Jugni</i>		dinner fight
dinner		anner jugni
Rules	Р	Rules P
$S \rightarrow VP$.05	$S \rightarrow VP$.05
$VP \longrightarrow Verb NP$.20	VP \rightarrow Verb NP NP .10
NP \rightarrow Det Nominal	.20	NP \rightarrow Det Nominal .20
Nominal \rightarrow Nominal Nour	ı .20	NP \rightarrow Nominal .15
Nominal \rightarrow Noun	.75	Nominal \rightarrow Noun .75
		Nominal \rightarrow Noun .75
Verb \rightarrow book	.30	Verb \rightarrow book .30
Det \rightarrow the	.60	Det \rightarrow the .60
Noun \rightarrow dinner	.10	Noun \rightarrow dinner .10
Noun \rightarrow flights	.40	Noun \rightarrow flights .40

P(T,S)=0.05*0.1*0.15*0.75*0.75* 0.3*0.6*0.1*0.4=6.1x10^-7

Formalizing Disambiguation

• Select T such that:

$$\hat{T}(S) = \underset{Ts.t, S=yield(T)}{\operatorname{argmax}} P(T)$$

- String of words S is *yield* of parse tree over S
- Select tree that maximizes probability of parse

Parsing Problem for PCFGs

• Select T such that:

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Parsing Problem for PCFGs

• Select T such that:

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- String of words S is *yield* of parse tree over S
- Select tree that maximizes probability of parse
- Extend existing algorithms: CKY & Earley
 - Most modern PCFG parsers based on CKY
 - Augmented with probabilities

Probabilistic CKY

- Like regular CKY
 - Assume grammar in Chomsky Normal Form (CNF)
 - Productions:
 - A -> B C or A -> w
 - Represent input with indices b/t words
 - E.g., $_0$ Book $_1$ that $_2$ flight $_3$ through $_4$ Houston $_5$

Probabilistic CKY

- Like regular CKY
 - Assume grammar in Chomsky Normal Form (CNF)
 - Productions:
 - A -> B C or A -> w
 - Represent input with indices b/t words
 - E.g., $_0$ Book $_1$ that $_2$ flight $_3$ through $_4$ Houston $_5$
- For input string length n and non-terminals V
 - Cell[i,j,A] in (n+1)x(n+1)xV matrix contains
 - Probability that constituent A spans [i,j]

Probabilistic CKY Algorithm

```
function PROBABILISTIC-CKY(words, grammar) returns most probable parse
                                                        and its probability
  for j \leftarrow from 1 to LENGTH(words) do
     for all \{A \mid A \rightarrow words[j] \in grammar\}
        table[j-1, j, A] \leftarrow P(A \rightarrow words[j])
     for i \leftarrow from j - 2 downto 0 do
          for k \leftarrow i+1 to j-1 do
                 for all \{A \mid A \rightarrow BC \in grammar, \}
                                  and table[i,k,B] > 0 and table[k, j,C] > 0 }
                        if (table[i,j,A] < P(A \rightarrow BC) \times table[i,k,B] \times table[k,j,C]) then
                             table[i,j,A] \leftarrow P(A \rightarrow BC) \times table[i,k,B] \times table[k,j,C]
                             back[i,j,A] \leftarrow \{k,B,C\}
     return BUILD_TREE(back[1, LENGTH(words), S]), table[1, LENGTH(words), S]
```

PCKY Grammar Segment

S	$\rightarrow NP VP$.80	Det	\rightarrow the	.40
NP	$\rightarrow Det N$.30	Det	$\rightarrow a$.40
VP	$\rightarrow V NP$.20	N	\rightarrow meal	.01
V	\rightarrow include	es .05	N	\rightarrow flight	.02

Det: 0.4		
[0,1]		

Det: 0.4			
[0,1]			
	N: 0.02		
	[1,2]		

Det: 0.4 [0,1]	NP: 0.3*0.4*0.02 =.0024 [0,2]		
	N: 0.02 [1,2]		

Det: 0.4 [0,1]	NP: 0.3*0.4*0.02 =.0024 [0,2]		
	N: 0.02 [1,2]		
		V: 0.05 [2,3]	

Det: 0.4 [0,1]	NP: 0.3*0.4*0.02 =.0024 [0,2]		
	N: 0.02	[1.3]	
		V: 0.05 [2,3]	

Det: 0.4 [0,1]	NP: 0.3*0.4*0.02 =.0024	IU 31	
		[0,3]	
	N: 0.02		
	[1,2]	[1,3]	
		V: 0.05	
		[2,3]	

Det: 0.4	NP: 0.3*0.4*0.02			
[0,1]	[0,2]	[0,3]		
	N: 0.02			
	[1,2]	[1,3]		
		V: 0.05		
		[2,3]		
			Det: 0.4	
			[3,4]	

Det: 0.4	NP: 0.3*0.4*0.02			
[U,1]	=.0024 [0,2]	[0,3]		
	N: 0.02			
	[1,2]	[1,3]		
		V: 0.05		
		[2,3]	[2,4]	
			Det: 0.4	
			[3,4]	

Det: 0.4	NP: 0.3*0.4*0.02			
[0,1]	=.0024 [0,2]	[0,3]		
	N: 0.02			
	[1,2]	[1,3]	[1,4]	
		V: 0.05		
		[2,3]	[2,4]	
			Det: 0.4	
			[3,4]	

Det: 0.4	NP: 0.3*0.4*0.02			
[0,1]	=.0024 [0,2]	[0,3]	[0,4]	
	N: 0.02			
	[1,2]	[1,3]	[1,4]	
		V: 0.05		
		[2,3]	[2,4]	
			Det: 0.4	
			[3,4]	

Det: 0.4 [0,1]	NP: 0.3*0.4*0.02 =.0024 [0,2]	[0,3]	[0,4]	
	N: 0.02 [1,2]	[1,3]	[1,4]	
		V: 0.05		
		[2,3]	[2,4]	
			Det: 0.4	
			[3,4]	
				N: 0.01 [4,5]

Det: 0.4 [0,1]	NP: 0.3*0.4*0.02 =.0024 [0,2]	[0,3]	[0,4]	
	N: 0.02 [1,2]	[1,3]	[1,4]	
		V: 0.05		
		[2,3]	[2,4]	
			Det: 0.4 [3,4]	NP: 0.3*0.4*0.01 =0.0012 [3.5]
				N: 0.01 [4,5]

Det: 0.4 [0,1]	NP: 0.3*0.4*0.02 =.0024 [0,2]	[0,3]	[0,4]	
	N: 0.02 [1,2]	[1,3]	[1,4]	
		V: 0.05 [2,3]	[2,4]	VP: 0.2*0.05* 0.0012=0.0 00012 [2,5]
			Det: 0.4 [3,4]	NP: 0.3*0.4*0.01 =0.0012 [3,5]
				N: 0.01 [4,5]

Det: 0.4 [0,1]	NP: 0.3*0.4*0.02 =.0024 [0,2]	[0,3]	[0,4]	S: 0.8* 0.000012* 0.0024 [0,5]
	N: 0.02 [1,2]	[1,3]	[1,4]	[1,5]
		V: 0.05 [2,3]	[2,4]	VP: 0.2*0.05* 0.0012=0.0 00012 [2,5]
			Det: 0.4 [3,4]	NP: 0.3*0.4*0.01 =0.0012 [3,5]
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Alternative: Learn probabilities by re-estimating
(Later)

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- Test:
 - (Small-med) Set of sentences w/parses (WSJ, 23)
 - 2416 sentences
 - Held out, used for final evaluation