Probabilistic CKY

Our bane: Ambiguity

- John saw Mary
  - Typhoid Mary
  - Phillips screwdriver Mary

  note how rare rules interact
- I see a bird
  - is this 4 nouns – parsed like “city park scavenger bird”?

  rare parts of speech, plus systematic ambiguity in noun sequences
- Time flies like an arrow
  - Fruit flies like a banana
  - Time reactions like this one
  - Time reactions like a chemist
  - *or is it just an NP?*

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  note how rare rules interact
- I see a bird
  - is this 4 nouns – parsed like “city park scavenger bird”?

  rare parts of speech, plus systematic ambiguity in noun sequences
- Time | flies like an arrow — NP VP
  - Fruit flies | like a banana — NP VP
  - Time | reactions like this one — V[stem] NP
  - Time reactions | like a chemist — S PP
  - *or is it just an NP?*

How to solve this combinatorial explosion of ambiguity?

1. First try parsing without any weird rules, throwing them in only if needed.
2. Better: every rule has a weight. A tree’s weight is total weight of all its rules. Pick the overall lightest parse of sentence.
3. Can we pick the weights automatically? We’ll get to this later …

time **1** flies **2** like **3** an **4** arrow **5**

	1	2	3	4	5
0	**NP 3** **Vst 3**				
1		**NP 4** **VP 4**			
2			**P 2** **V 5**		
3				**Det 1**	

1 S → NP VP
6 S → Vst NP
2 S → S PP
1 VP → V NP
2 VP → VP PP
1 NP → Det N
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time **1** flies **2** like **3** an **4** arrow **5**

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	time 1	flies 2	like 3	an 4	arrow 5
0	NP 3 Vst 3	NP 10			
1		NP 4 VP 4			
2			P 2 V 5		
3				Det 1	

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1 VP → V NP
2 VP → VP PP

1 NP → Det N
2 NP → NP PP
3 NP → NP NP

0 PP → P NP

	time 1	flies 2	like 3	an 4	arrow 5
0	NP 3 Vst 3	NP 10 S 8			
1		NP 4 VP 4			
2			P 2 V 5		
3				Det 1	

1 S → NP VP
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	time 1	flies 2	like 3	an 4	arrow 5
0	NP 3 Vst 3	NP 10 S 8 S 13			
1		NP 4 VP 4			
2			P 2 V 5		
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	time 1	flies 2	like 3	an 4	arrow 5
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1		NP 4 VP 4			
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1		NP 4 VP 4			
2			P 2 V 5		
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	time 1	flies 2	like 3	an 4	arrow 5
0	NP 3 Vst 3	NP 10 S 8 S 13			
1		NP 4 VP 4			
2			P 2 V 5		PP 12
3				Det 1	NP 10

1 S → NP VP
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2 VP → VP PP

1 NP → Det N
2 NP → NP PP
3 NP → NP NP

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	time 1	flies 2	like 3	an 4	arrow 5
0	NP 3 Vst 3	NP 10 S 8 S 13			
1		NP 4 VP 4			
2			P 2 V 5		PP 12 VP 16
3				Det 1	NP 10

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	time 1	flies 2	like 3	an 4	arrow 5
0	NP 3 Vst 3	NP 10 S 8 S 13			
1		NP 4 VP 4			
2			P 2 V 5		PP 12 VP 16
3				Det 1	NP 10

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	time 1	flies 2	like 3	an 4	arrow 5
0	NP 3 Vst 3	NP 10 S 8 S 13			
1		NP 4 VP 4			NP 18
2			P 2 V 5		PP 12 VP 16
3				Det 1	NP 10

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3				Det 1	NP 10

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time 1 flies 2 like 3 an 4 arrow 5

0	NP 3 Vst 3	NP 10 S 8 S 13			
1		NP 4 VP 4			NP 18 S 21 VP 18
2			P 2 V 5		PP 12 VP 16
3				Det 1	NP 10

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2 NP → NP PP
3 NP → NP NP
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time 1 flies 2 like 3 an 4 arrow 5

0	NP 3 Vst 3	NP 10 S 8 S 13			NP 24
1		NP 4 VP 4			NP 18 S 21 VP 18
2			P 2 V 5		PP 12 VP 16
3				Det 1	NP 10

1 S → NP VP
6 S → Vst NP
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2 VP → VP PP
1 NP → Det N
2 NP → NP PP
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time 1 flies 2 like 3 an 4 arrow 5

0	NP 3 Vst 3	NP 10 S 8 S 13			NP 24 S 22
1		NP 4 VP 4			NP 18 S 21 VP 18
2			P 2 V 5		PP 12 VP 16
3				Det 1	NP 10

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time 1 flies 2 like 3 an 4 arrow 5

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1		NP 4 VP 4			NP 18 S 21 VP 18
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2			P 2 V 5		PP 12 VP 16
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time 1 flies 2 like 3 an 4 arrow 5

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1		NP 4 VP 4			NP 18 S 21 VP 18
2			P 2 V 5		PP 12 VP 16
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time 1 flies 2 like 3 an 4 arrow 5

0	NP 3 Vst 3	NP 10 S 8 S 13			NP 24 S 22 S 27 NP 24 S 27
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time 1 flies 2 like 3 an 4 arrow 5

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Follow backpointers …

S

time 1 flies 2 like 3 an 4 arrow 5

0	NP 3 Vst 3	NP 10 S 8 S 13			NP 24 S 22 S 27 NP 24 S 27 S 22 S 27
1		NP 4 VP 4			NP 18 S 21 VP 18
2			P 2 V 5		PP 12 VP 16
3				Det 1	NP 10

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S
NP VP

time 1 flies 2 like 3 an 4 arrow 5

0	NP 3 Vst 3	NP 10 S 8 S 13			NP 24 S 22 S 27 NP 24 S 27 S 22 S 27
1		NP 4 VP 4			NP 18 S 21 VP 18
2			P 2 V 5		PP 12 VP 16
3				Det 1	NP 10

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S
NP VP
VP PP

time 1 flies 2 like 3 an 4 arrow 5

0	NP 3 Vst 3	NP 10 S 8 S 13			NP 24 S 22 S 27 NP 24 S 27 S 22 S 27
1		NP 4 VP 4			NP 18 S 21 VP 18
2			P 2 V 5		PP 12 VP 16
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time 1 flies 2 like 3 an 4 arrow 5

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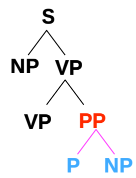
1		NP 4 VP 4			NP 18 S 21 VP 18
2			P 2 V 5		PP 12 VP 16
3				Det 1	NP 10



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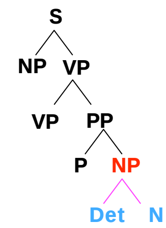
0	NP 3 Vst 3	NP 10 S 8 S 13			NP 24 S 22 S 27 NP 24 S 27 S 22 S 27
1		NP 4 VP 4			NP 18 S 21 VP 18
2			P 2 V 5		PP 12 VP 16
3				Det 1	NP 10



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Which entries do we *need*?

time 1 flies 2 like 3 an 4 arrow 5

0	NP 3 Vst 3	NP 10 S 8 S 13			NP 24 S 22 S 27 NP 24 S 27 S 22 S 27
1		NP 4 VP 4			NP 18 S 21 VP 18
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time 1 flies 2 like 3 an 4 arrow 5

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Not worth keeping …

time 1 flies 2 like 3 an 4 arrow 5

0	NP 3 Vst 3	NP 10 S 8 S 13			NP 24 S 22 S 27 NP 24 S 27 S 22 S 27
1		NP 4 VP 4			NP 18 S 21 VP 18
2			P 2 V 5		PP 12 VP 16
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… since it just breeds worse options

time 1 flies 2 like 3 an 4 arrow 5

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1		NP 4 VP 4			NP 18 S 21 VP 18
2			P 2 V 5		PP 12 VP 16
3				Det 1	NP 10

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Keep only best-in-class!

	time 1	flies 2	like 3	an 4	arrow 5
0	NP 3 Vst 3	NP 10 S 8 S 13			NP 24 S 22 S 27 NP 24 S 27 S 22 S 27
1		NP 4 VP 4			NP 18 S 21 VP 18
2			P 2 V 5		PP 12 VP 16
3				Det 1	NP 10

inferior stock

1 S → NP VP
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2 NP → NP PP
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Keep only best-in-class!

(and its backpointers so you can recover best parse)

	time 1	flies 2	like 3	an 4	arrow 5
0	NP 3 Vst 3	NP 10 S 8			NP 24 S 22
1		NP 4 VP 4			NP 18 S 21 VP 18
2			P 2 V 5		PP 12 VP 16
3				Det 1	NP 10
4					N 8

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1 NP → Det N
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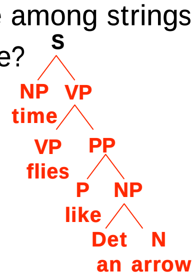
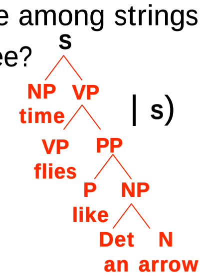
Probabilistic Trees

- Instead of lightest weight tree, take highest probability tree
- Given any tree, your assignment 1 generator would have some probability of producing it!
- Just like using n-grams to choose among strings ...
- What is the probability of this tree?



Probabilistic Trees

- Instead of lightest weight tree, take highest probability tree
- Given any tree, your assignment 1 generator would have some probability of producing it!
- Just like using n-grams to choose among strings ...
- What is the probability of this tree?
- You rolled a lot of independent dice ...

p( | s)

Chain rule: One word at a time

p(time flies like an arrow)
= p(time)
* p(flies | time)
* p(like | time flies)
* p(an | time flies like)
* p(arrow | time flies like an)

Chain rule + backoff (to get trigram model)

p(time flies like an arrow)
= p(time)
* p(flies | time)
* p(like | time flies)
* p(an | time flies like)
* p(arrow | time flies like an)

Chain rule – written differently

p(time flies like an arrow)
= p(time)
* p(time flies | time)
* p(time flies like | time flies)
* p(time flies like an | time flies like)
* p(time flies like an arrow | time flies like an)

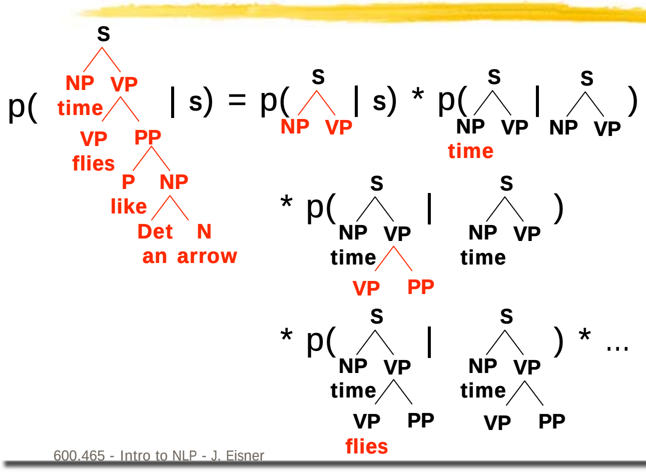
Proof: p(x,y | x) = p(x | x) * p(y | x, x) = 1 * p(y | x)

Chain rule + backoff

p(time flies like an arrow)
= p(time)
* p(time flies | time)
* p(time flies like | time flies)
* p(time flies like an | time flies like)
* p(time flies like an arrow | time flies like an)

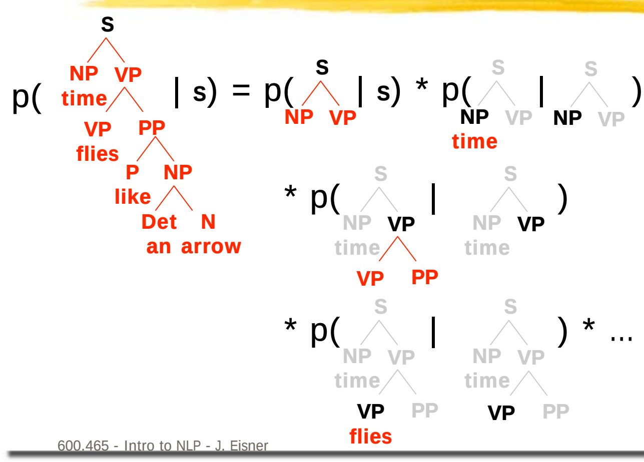
Proof: p(x,y | x) = p(x | x) * p(y | x, x) = 1 * p(y | x)

Chain rule: One node at a time



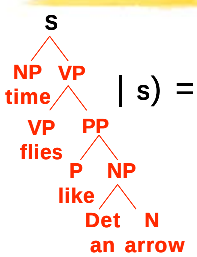
Chain rule + backoff

model you used in homework 1! (called "PCFG")



Simplified notation

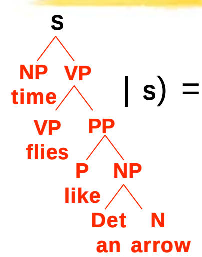
model you used in homework 1! (called "PCFG")

p( | s) = p(S → NP VP | S) * p(NP → flies | NP)

* p(VP → VP NP | VP)

* p(VP → flies | VP) * ...

Already have a CKY alg for weights …

w( | s) = w(S → NP VP) + w(NP → flies | NP)

+ w(VP → VP NP)

+ w(VP → flies) + …

Just let w(X → Y Z) = -log p(X → Y Z | X)
Then lightest tree has highest prob

	time 1	flies 2	like 3	an 4	arrow 5
0	NP 3 Vst 3	NP 10 S 8 S 13			NP 24 S 22 S 27 NP 24 S 27 S 22 S 27
1		NP 4 VP 4			NP 18 S 21 VP 18
2			P 2 V 5		PP 12 VP 16
3				Det 1	NP 10

2^{-8} multiply to get 2^{-22} 2^{-12} 2^{-2}

1 S → NP VP
6 S → Vst NP
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Need only best-in-class to get best parse

	time 1	flies 2	like 3	an 4	arrow 5
0	NP 3 Vst 3	NP 10 S 8 S 13			NP 24 S 22 S 27 NP 24 S 27 S 22 S 27
1		NP 4 VP 4			NP 18 S 21 VP 18
2			P 2 V 5		PP 12 VP 16
3				Det 1	NP 10

2^{-13} 2^{-8} multiply to get 2^{-22} 2^{-12} 2^{-2}

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1 NP → Det N
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Why probabilities not weights?

- We just saw probabilities are really just a special case of weights …
- … *but* we can estimate them from training data by counting and smoothing! Yay!
- Warning: What kind of training corpus do we need?

A slightly different task

- Been asking: What is probability of generating a given *tree* with your homework 1 generator?
  - To pick tree with highest prob: useful in parsing.
- But could also ask: What is probability of generating a given *string* with the generator? *(i.e., with the –t option turned off)*
  - To pick string with highest prob: useful in speech recognition, as substitute for an n-gram model.
    - ("Put the file in the folder" vs. "Put the file and the folder")
  - To get prob of generating string, must add up probabilities of all trees for the string …

Could just add up the parse probabilities

	time 1	flies 2	like 3	an 4	arrow 5
0	NP 3 Vst 3	NP 10 S 8 S 13			NP 24 S 22 S 27 NP 24 S 27 S 22 S 27
1		NP 4 VP 4			NP 18 S 21 VP 18
2			P 2 V 5		PP 12 VP 16
3				Det 1	NP 10

2^{-22} 2^{-27} 2^{-27} 2^{-22} 2^{-27}

oops, back to finding exponentially many parses

1 S → NP VP
6 S → Vst NP
2 S → S PP
1 VP → V NP
2 VP → VP PP
1 NP → Det N
2 NP → NP PP
3 NP → NP NP
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Any more efficient way?

	time 1	flies 2	like 3	an 4	arrow 5
0	NP 3 Vst 3	NP 10 S 2^{-8} S 2^{-13}			NP 24 S 22 S 27 NP 24 S 27 S 2^{-22} S 2^{-27}
1		NP 4 VP 4			NP 18 S 21 VP 18
2			P 2 V 5		PP 2^{-12} VP 16
3				Det 1	NP 10

1 S → NP VP
6 S → Vst NP
2^{-2} S → S PP
1 VP → V NP
2 VP → VP PP
1 NP → Det N
2 NP → NP PP
3 NP → NP NP
0 PP → P NP

Add as we go … (the “inside algorithm”)

time 1 flies 2 like 3 an 4 arrow 5

	1	2	3	4	5
0	**NP 3** **Vst 3**	**NP 10** **S** $2^{-8}+2^{-13}$			**NP 24** **S 22** **S 27** **NP 24** **S 27** **S** 2^{-22} $+2^{-27}$
1		**NP 4** **VP 4**			**NP 18** **S 21** **VP 18**
2			**P 2** **V 5**		**PP** 2^{-12} **VP 16**
3				**Det 1**	**NP 10**

1 S → NP VP
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Add as we go … (the “inside algorithm”)

time 1 flies 2 like 3 an 4 arrow 5

	1	2	3	4	5
0	**NP 3** **Vst 3**	**NP 10** **S** $2^{-8}+2^{-13}$			**NP** 2^{-22} $+2^{-27}$ **S** 2^{-22} $+2^{-27}$ $+2^{-27}$ $+2^{-22}$ $+2^{-27}$
1		**NP 4** **VP 4**			**NP 18** **S 21** **VP 18**
2			**P 2** **V 5**		**PP** 2^{-12} **VP 16**
3				**Det 1**	**NP 10**

1 S → NP VP
6 S → Vst NP
2^{-2} S → S PP
1 VP → V NP
2 VP → VP PP
1 NP → Det N
2 NP → NP PP
3 NP → NP NP
0 PP → P NP