LING/C SC 581:

Advanced Computational Linguistics

Lecture 12

Today's Topics

- Homework 5 Review
- CKY Parsing algorithm
  - Dynamic Programming
  - Chomsky Normal Form (CNF)

Homework 5 Review

- Contrast 1 vs 2:
  1. John knew an untrue story about him.
  2. John overheard an untrue story about him.
- Asking ChatGPT the *right* question is key:
  - Who is *him*?
  - Who does *him* refer to?
  - Who is the story about?
  - Responses may vary
- *So how can we conclude anything about ChatGPT in these cases*?

Reflexives and Pronouns

- (Reuland 2010; 93)
  - Max knows which pictures of himself Lucie likes
  - Max knows which pictures of herself Lucie likes
- *What do you think of these*?
  - Max knows which pictures of him/ him Lucie likes
  - Max knows which pictures of ??her/ her Lucie likes
- *Or these*?
  - Max knows *him/ him
  - Max knows himself

The Pronoun *it*

- How about pronominal *it*?
    1. The AI knows which pictures of it the robot likes
    2. The AI knows which pictures of it the robot likes
    3. The AI knows which pictures of it the robot likes

Homework 5 Review

ChatGPT 3.5

You
John knew an untrue story about him. Who is the story about?

ChatGPT
The statement "John knew an untrue story about him" suggests that John is aware of a false story circulating about himself. Therefore, the story is about John himself. However, without further context, it's unclear what the specific untrue story might be or what it entails.

Homework 5 Review

ChatGPT 3.5

You

John knew an untrue story about him. Who is him?

ChatGPT

Without more context, it's impossible to determine who "him" refers to. The name "John" is mentioned, but it's unclear who "him" is in relation to John. Can you provide more information or clarify the context of the story?

Homework 5 Review

ChatGPT 3.5

You
John knew an untrue story about him. Who does him refer to?

ChatGPT
In the phrase "John knew an untrue story about him," the word "him" likely refers to someone other than John. It suggests that there is a story circulating about a person other than John, and John is aware of this false narrative. Without further context, it's difficult to determine exactly who "him" refers to. It could be a friend, acquaintance, or someone else entirely.

Homework 5 Review

ChatGPT 3.5

You
Bill is an honest man. John knew an untrue story about him. Who is the story about?

ChatGPT
The story is about Bill. John knew an untrue story about Bill.

Homework 5 Review

ChatGPT 3.5

You

Bill is an honest man. John knew an untrue story about himself. Who is the story about?

ChatGPT

The story is about John. John knew an untrue story about himself, indicating that the story is about him.

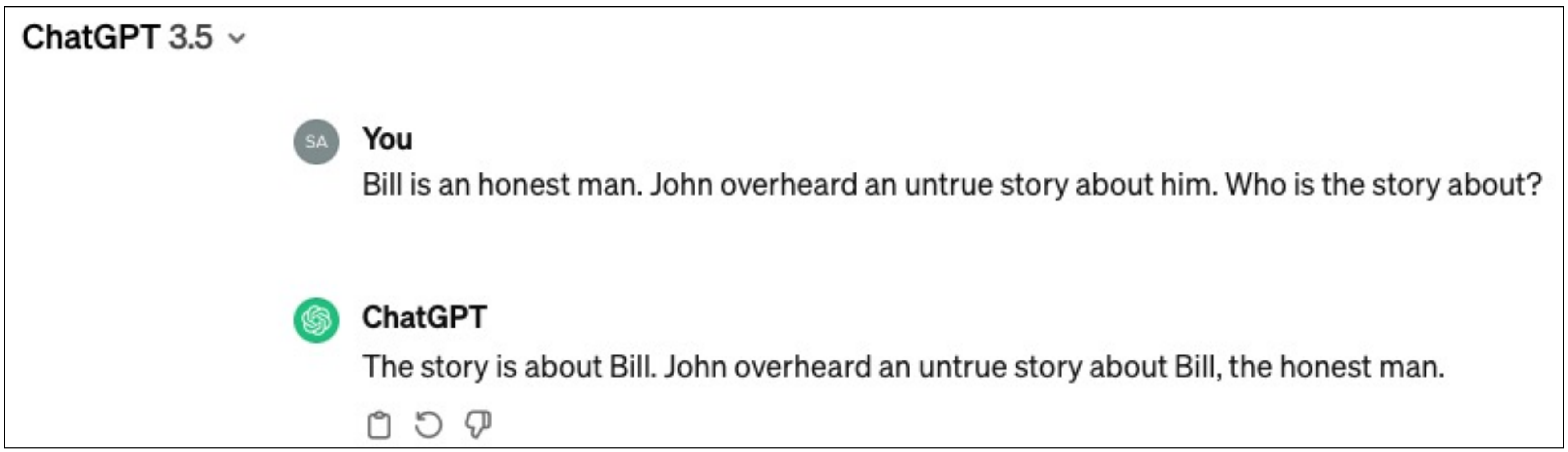
Homework 5 Review

ChatGPT 3.5

You
John overheard an untrue story about him. Who is the story about?

ChatGPT
The story is about John, as indicated in the prompt. John overheard an untrue story about himself. Therefore, the subject of the story is John.

Homework 5 Review



Homework 5 Review

ChatGPT 3.5

You

Bill is an honest man. John overheard an untrue story about himself. Who is the story about?

ChatGPT

The story is about John. John overheard an untrue story about himself, indicating that the story is about him.

The Pronoun *it*

SA **You**

The AI knows which pictures of it the robot likes. What does it refer to here?

ChatGPT

The phrase "the AI knows which pictures of it the robot likes" seems to refer to a scenario where an artificial intelligence system (AI) is able to recognize or determine which images of itself a robot prefers or finds appealing. In this context, "the AI" likely denotes a sophisticated computational system capable of processing and understanding visual information, while "the robot" refers to a physical or virtual machine that interacts with its environment, possibly equipped with sensors and other technologies for perceiving and interpreting images. The statement suggests a level of self-awareness or preference recognition within the AI, implying it can discern the preferences or aesthetic judgments of the robot regarding images of itself.

The Pronoun *it*

SA

You

The AI knows which pictures of it the robot likes. What is in the pictures?

ChatGPT

As an AI language model, I don't have personal experiences or preferences, so I don't have the capability to like or dislike pictures. However, if you're referring to a hypothetical scenario where an AI is programmed to recognize certain images or patterns that it finds appealing, it would depend entirely on how the AI was designed and what criteria were used to determine what it likes. This could include various visual features, colors, shapes, or even more abstract concepts depending on the programming and training data.

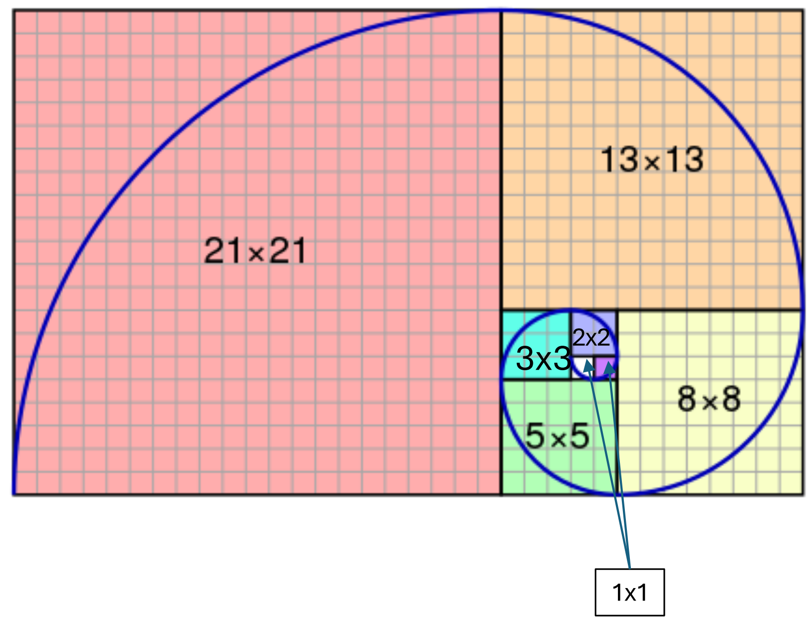
Context-Free Grammar Parsing

- Algorithm:
  - use Prolog's top-down, left-to-right depth-first search
  - (avoid left recursion problems: use our grammar transformation)
- There are lots of algorithms for parsing context-free rules
  - In this course, we'll examine two
  - Today: CKY – because of the 2D table (*it's used for tabular parsing*)
  - the 2D table is computationally efficient (*memorization of partial results*)
    - particularly useful when there is structural ambiguity
    - e.g. … *with a telescope*

Memorization aka Dynamic Programming

- A general computational trick (also used in math)
- Example:
  - 0,1,1,2,3,5,8,13,21,34,55,89,…
  - Fibonacci sequence
    - f(0)=0,
    - f(1)=1,
    - f(n)=f(n-1)+f(n-2) for n>1
- Example:
  - f(5) = f(4) + f(3)
  - = f(3) + f(2) + f(3)
  - = 2 + 1 + 2

Fibonacci Spiral: adapted from wikipedia



Memorization aka Dynamic Programming

- Not a standard feature of Prolog
  - Program: `fibonacci.prolog` implements
  - Fibonacci sequence
    - f(0)=0,
    - f(1)=1,
    - f(n)=f(n-1)+f(n-2) for n>1
  - (*no* {…} *needed here, it's not a grammar*)

```
%% f(N, M) M is Fibonacci N
f(0, 0).
f(1, 1).
f(N, M) :- N > 1, N1 is N-1, f(N1,M1), N2 is N-2, f(N2,M2), M is M1+M2.
```

Memorization aka Dynamic Programming

- Correct but inefficient

```
?- [fibonacci].
true.

?- f(0, N).
N = 0 ;
false.
?- f(1, N).
N = 1 ;
false.

?- f(5, N).
N = 5 ;
false.

?- f(6, N).
N = 8 ;
false.

?- f(7, N).
N = 13

?- f(8, N).
N = 21 ;
false.
```

Memorization aka Dynamic Programming

```
?- spy(f).
% Spy point on f/2
true.

[debug]  ?- f(5, N).
   Call: (10) f(5, _34086) ? leap
   Call: (11) f(4, _35386) ? leap
   Call: (12) f(3, _36288) ? leap
   Call: (13) f(2, _37190) ? leap
   Call: (14) f(1, _38092) ? leap
   Exit: (14) f(1, 1) ? leap
   Call: (14) f(0, _39886) ? leap
   Exit: (14) f(0, 0) ? leap
   Exit: (13) f(2, 1) ? leap
   Call: (13) f(1, _42578) ? leap
   Exit: (13) f(1, 1) ? leap
   Exit: (12) f(3, 2) ? leap
   Call: (12) f(2, _45270) ? leap
   Call: (13) f(1, _46172) ? leap
   Exit: (13) f(1, 1) ? leap
   Call: (13) f(0, _47966) ? leap
   Exit: (13) f(0, 0) ? leap
   Exit: (12) f(2, 1) ? leap
   Exit: (11) f(4, 3) ? leap
   Call: (11) f(3, _51556) ? leap
   Call: (12) f(2, _52458) ? leap
   Call: (13) f(1, _53360) ? leap
   Exit: (13) f(1, 1) ? leap
   Call: (13) f(0, _55154) ? leap
   Exit: (13) f(0, 0) ? leap
   Exit: (12) f(2, 1) ? leap
   Call: (12) f(1, _57846) ? leap
   Exit: (12) f(1, 1) ? leap
   Exit: (11) f(3, 2) ? leap
   Exit: (10) f(5, 5) ? leap
N = 5 ;
   Fail: (12) f(1, _57846) ? leap
   Fail: (13) f(0, _55154) ? leap
   Fail: (13) f(1, _53360) ? leap
   Fail: (12) f(2, _52458) ? leap
   Fail: (11) f(3, _51556) ? leap
   Fail: (13) f(0, _47966) ? leap
   Fail: (13) f(1, _46172) ? leap
   Fail: (14) f(0, _39886) ? leap
   Fail: (14) f(1, _38092) ? leap
   Fail: (13) f(2, _37190) ? leap
   Fail: (12) f(3, _36288) ? leap
   Fail: (11) f(4, _35386) ? leap
   Fail: (10) f(5, _34086) ? leap
false.
```

type l for leap

Computes f(2) = 1 three times!

CKY Algorithm

CKY = Cocke-Kasami-Younger, sometimes CYK

- A **tabular method** (*dynamic programming*) for parsing Context-Free Grammars (CFG) (JM textbook, 13.4)
- Works with CFGs expressed in **Chomsky Normal Form** (CNF) format (JM textbook, 12.5):
  1. `x --> y, z.`
  2. `x --> [w].`
  3. `s --> [].` (`s` start symbol) (optional rule, not for non-start symbols)
  - Note 1:
    - all CFGs can be expressed in this format, although it destroys linguistic structure (*which can be rebuilt*).
  - Note 2:
    - cf. regular grammars: rule 1 vs. `x --> [w], y.` or `x --> y, [w].`
  - Note 3:
    - other normal forms are also possible:
    - e.g. **Greibach Normal Form** (GNF): `x --> [a], y..z`
    - non-left recursive!

Chomsky Normal Form (CNF)

- **Conversion steps:**
  1. new start symbol **s_0 --> s.**
     (**s** original start symbol) to cope with possible empty derivation.
     s_0 is the only nonterminal allowed to have form **s_0 --> s**
  2. Make new nonterminal for terminals on the RHS:
     x --> … [w] … (|RHS| > 1)
     becomes **x -->** … **x_w** … and **x_w --> [w].** (**x_w** a new nonterminal)
  3. Binarize the RHS:
     x --> y_1, …**,y_n.** (|RHS| > 2)
     becomes a cascading sequence of binary rules:
     x --> y_1, x_1. x_1 --> y_2, x_2. … **x_{n-1} --> y_{n-1}, y_n.**
  4. Delete epsilon rules:
     for each instance of **x --> [].** and **y -->** … **x** …
     add a copy without **x**, i.e**. y -->** … … then delete **x --> [].**
  5. Remove singleton rules:
     remove **x --> y.**(exception: **x** cannot be **s_0**) Replace **x** by **y** in other rules.

Chomsky Normal Form (CNF)

- Example:

```
1. s --> [].
2. s --> a.
3. a --> a, b, b, a.
4. a --> [a].
5. b --> [b], c, [b].
6. c --> [c].
```

1. []
2. [a]
3. [a, b, c, b, b, c, b, a]
4. [a, b, c, b, b, c, b, a, b, c, b, b, c, b, a]
5. [a, b, c, b, b, c, b, a, b, c, b, b, c, b, a, b, c, b, b, c, b, a]
6. ...

- Let's convert this grammar to CNF.

Chomsky Normal Form (CNF)

- Example:

```
1. s --> [].
2. s --> a.
3. a --> a, b, b, a.
4. a --> [a].
5. b --> [b], c, [b]
6. c --> [c].
```

```
1.  s0 --> s.
2.  s --> [].
3.  s --> a.
4.  a --> a, bba.
5.  bba --> b, ba.
6.  ba --> b, a.
7.  a --> [a].
8.  b --> b2, cb.
9.  b2 --> [b].
10. cb --> c, b2.
11. c --> [c].
```

```
1.  s0 --> [].
2.  s0 --> a.
3.  a --> a, bba.
4.  bba --> b, ba.
5.  ba --> b, a.
6.  a --> [a].
7.  b --> b2, cb.
8.  b2 --> [b].
9.  cb --> c, b2.
10. c --> [c].
```

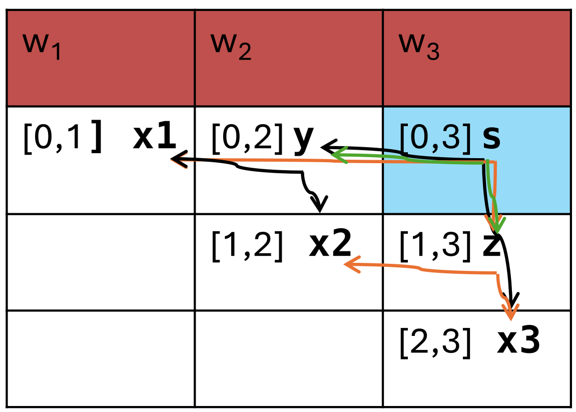
CKY Algorithm

- Grammar transformed into:
```
1. x --> y, z.
2. x --> [w].
```
- Given a sentence $w_1,..,w_n$, represent the possible parsings of this string by a table, where each cell may hold a nonterminal covering a substring.
- **Example**: $^0\ w_1\ ^1\ w_2\ ^2\ w_3\ ^3$ (0..3 are position markers)

w_1	w_2	w_3
[0,1]	[0,2]	[0,3]
	[1,2]	[1,3]
		[2,3]

CKY Algorithm

- Chomsky Normal Form (CNF) – binary branching
- 2D table




```
s --> y, x3.
s --> x1, z.
s --> y, z.
y --> x1, x2.
z --> x2, x3.
x1 --> [w1].
x2 --> [w2].
x3 --> [w3].
```

CKY Algorithm

- Bottom-up:

w_1	w_2	w_3
[0,1] **x1**	[0,2]	[0,3]
	[1,2] **x2**	[1,3]
		[2,3] **x3**

```
x1 --> [w1].
x2 --> [w2].
x3 --> [w3].
```

CKY Algorithm

- Bottom-up: 0 w_1 1 w_2 2 w_3 3

w_1	w_2	w_3
[0,1] **x1**	[0,2] **y**	[0,3]
	[1,2] **x2**	[1,3] **z**
		[2,3] **x3**

```
y --> x1, x2.
z --> x2, x3.
```

CKY Algorithm

- Bottom-up:

w_1	w_2	w_3
[0,1] **x1**	[0,2] **y**	[0,3]
	[1,2] **x2**	[1,3] **z**
		[2,3] **x3**

```
s --> y, z.
```

s is not derivable because **[0,2]y** overlaps with **[1,3]z**

CKY Algorithm

- Bottom-up:

w_1	w_2	w_3
[0,1] **x1**	[0,2] **y**	[0,3] **s**
	[1,2] **x2**	[1,3] **z**
		[2,3] **x3**

```
s --> x1, z.
```

[0,3]s is derivable because **[0,1]x1** concats with **[1,3]z**

CKY Algorithm

- Bottom-up:

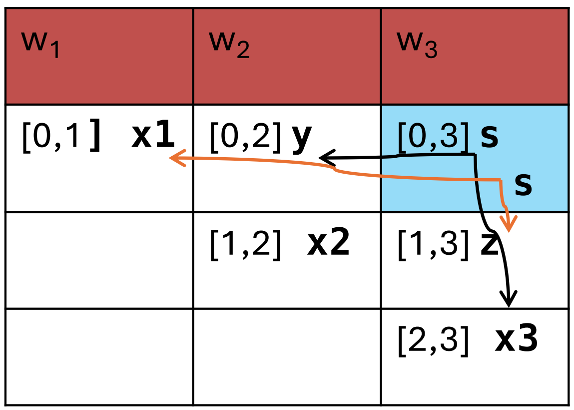
w_1	w_2	w_3
[0,1] **x1**	[0,2] **y**	[0,3] **s**
	[1,2] **x2**	[1,3] **z**
		[2,3] **x3**

```
s --> y, x3.
```

[0,3]s is derivable because **[0,2]y** concats with **[2,3]x3**

CKY Algorithm

- Backpointers indicate parse:



CKY Algorithm


```
function CKY-PARSE(words, grammar) returns table

  for j ← from 1 to LENGTH(words) do
      table[j − 1, j] ← {A | A → words[j] ∈ grammar}
      for i ← from j − 2 downto 0 do
          for k ← i + 1 to j − 1 do
              table[i,j] ← table[i,j] ∪
                           {A | A → BC ∈ grammar,
                                B ∈ table[i,k],
                                C ∈ table[k, j]}
```

Figure 13.10 The CKY algorithm.

CKY Algorithm and Prolog Grammar Rules

- CNF:
  - we can make conversion *transparent*
  - because we can decide what to produce as a parse tree using an extra argument, cf. *left recursive parse transformation*
- Table representation:
  - (if using Prolog) must be careful about variable bindings:
  - solution: make fresh copies of variables
- Agreement (*feature propagation*):
  - must save all arguments into table
  - and relink up properly, e.g.
  - `np(np(DT,NN)) --> dt(DT,Num), nn(NN,Num).`

nltk book: chapter 8

- Link:
  - https://www.nltk.org/book/ch08.html
- Steps:

```
$ python
Python 3.9.12 (main, Jun  1 2022, 06:34:44)
>>> import nltk
>>> cnf = open('cnf.txt').read()
>>> cnf
"s -> y x3\ns -> x1 z\ns -> y z\ny -> x1 x2\nz -> x2 x3\nx1 -> 'w1'\nx2 -> 'w2'\nx3 -> 'w3'\n"
>>> cfg = nltk.CFG.fromstring(cnf)
>>> cfg
<Grammar with 8 productions>
>>> p = nltk.ChartParser(cfg)
```

cnf.txt on website

```
s -> y x3
s -> x1 z
s -> y z
y -> x1 x2
z -> x2 x3
x1 -> 'w1'
x2 -> 'w2'
x3 -> 'w3'
```

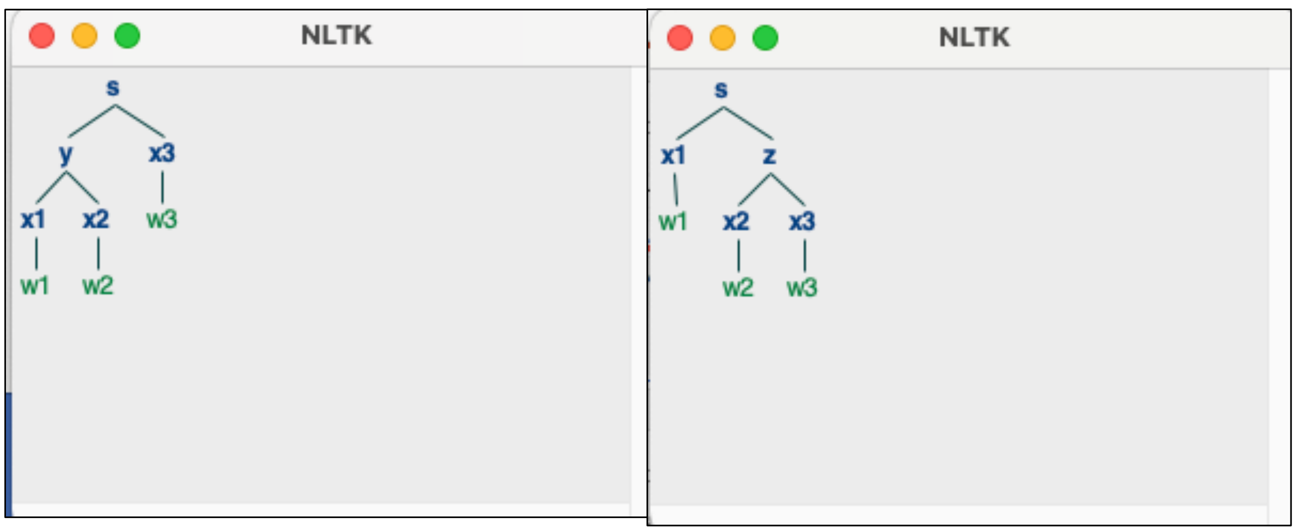
cnf is a string,
cfg is a grammar

nltk book: chapter 8

- To parse, supply a pre-tokenized sentence (a list):

```
• >>> for tree in p.parse(['w1','w2','w3']):
• ...     tree.draw()
• ...
• >>>
```

<TAB> to indent, and need a blank line as well

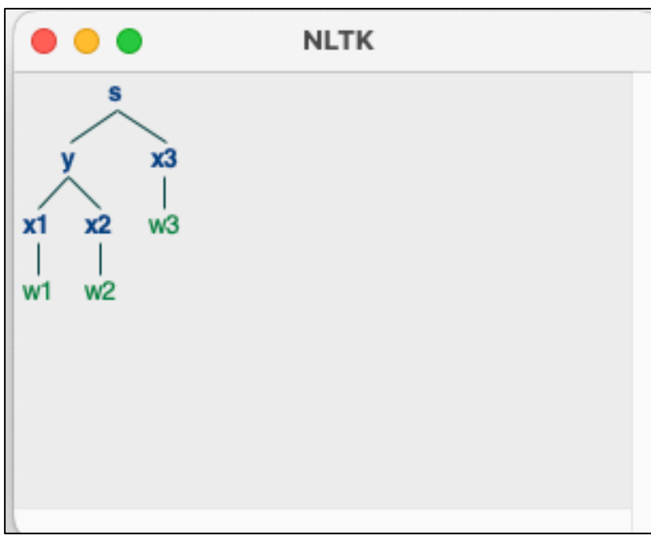


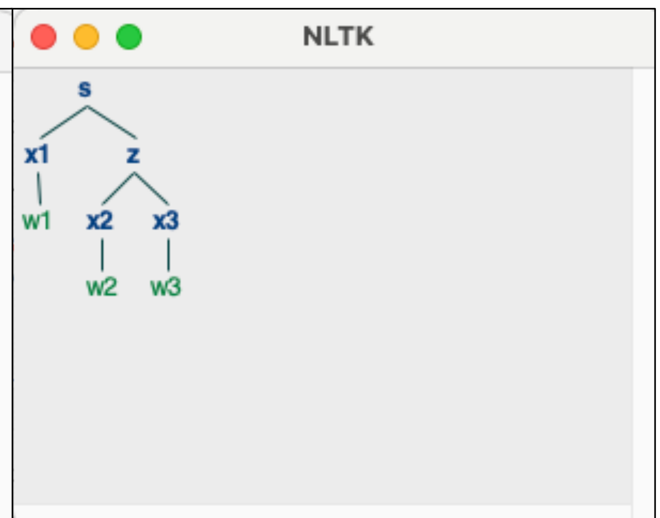
nltk book: chapter 8

- To perform parsing, call:
  - `p.parse(list)`   p is a parser
- But, first define p, the parser you want to use.
- Different parsing strategies available, e.g.:
  1. `p = nltk.ChartParser(cfg)`
  2. `p = nltk.ShiftReduceParser(cfg)`   *doesn't do backtracking*
  3. `p = nltk.RecursiveDescentParser(cfg)` *doesn't do left recursion*

nltk book: chapter 8

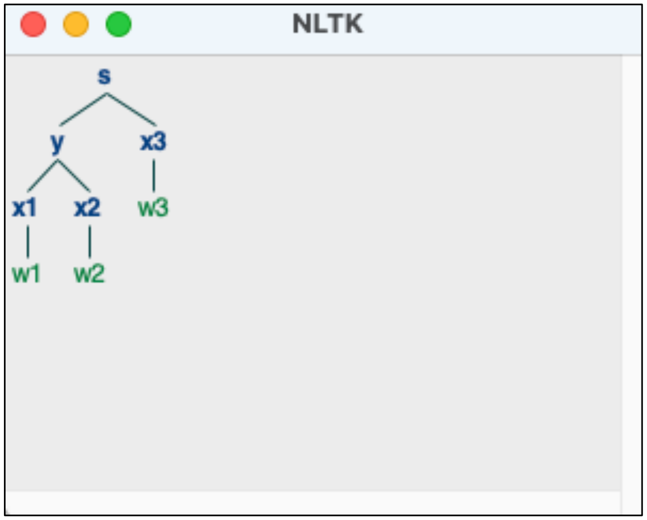
- Same sentence, different parser:
- `>>> p = nltk.RecursiveDescentParser(cfg)`
- `>>> for tree in p.parse(['w1','w2','w3']):`
- `...     tree.draw()`
- `...`
- `>>>`





nltk book: chapter 8

- Same sentence, different parser:
- `>>> p = nltk.ShiftReduceParser(cfg)`
- `>>> for tree in p.parse(['w1','w2','w3']):`
- `...     tree.draw()`
- `...`
- `>>>`



nltk book: chapter 8

- Notes on grammar format:
  - plain text file
  - 1st line defines the start-symbol (S)
  - -> is the rewrite symbol (cf. Prolog `-->`)
  - space between symbols (cf. Prolog `,`)
  - lexical items are quoted, e.g. 'I' (cf. Prolog `[word]`)
  - *you cannot combine grammatical categories with lexical items*
    - PP -> 'of' NP (disallowed, cf. `pp --> [of], np.`)
  - *you are not permitted multi-word lexical items*
    - not ok: NP -> 'New York'
    - ok: NP -> 'New_York' (cf. Prolog `[new,york]`)