LING/C SC 581:
Advanced Computational Linguistics

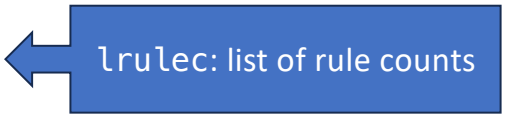
Lecture 24

Today's Topic

- Last Time:
  - `t.productions()` (= *phrase structure rules*)
  - `p.lhs()`/`p.rhs()`
  - `len(p.rhs())` (= # children)
  - `p.is_nonlexical()`/`p.is_lexical()`
  - `p.lhs().symbol()` (nonterminal symbol)
- A CFG experiment with the ptb:
  - *CFG = Context-free Grammar*
  - *How many common ptb rules do we need to parse a sentence*?

Distribution of Productions

```
>>> import matplotlib.pyplot as plt
>>> import numpy as np
>>> from scipy.stats import norm
>>> from statistics import mean, stdev

>>> from nltk.corpus import ptb
>>> trees = ptb.parsed_sents()
>>> len(trees)
73451
>>> lrulec = [len(t.productions()) for t in trees]
>>> sum(lrulec)
3131242
```



Distribution of Productions

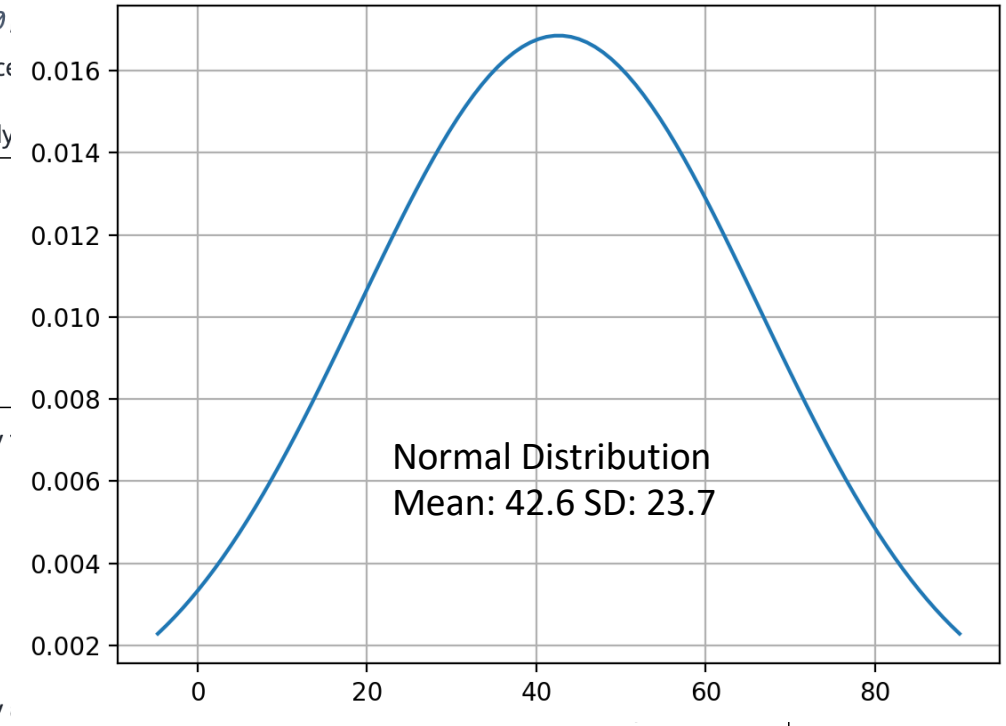
```
>>> mean(lrulec)
42.63035220759418
>>> stdev(lrulec)
23.671107782972243
>>> m = mean(lrulec)
>>> sd = stdev(lrulec)
>>> x = np.linspace(m-2*sd,m+2*sd,100)

>>> plt.plot(x,norm.pdf(x,m,sd))

>>> plt.grid()
>>> plt.show()
```

numpy.linspace(st

***dtype**=None, **axis**=0*

Return evenly space

Returns *num* evenly



The probability density

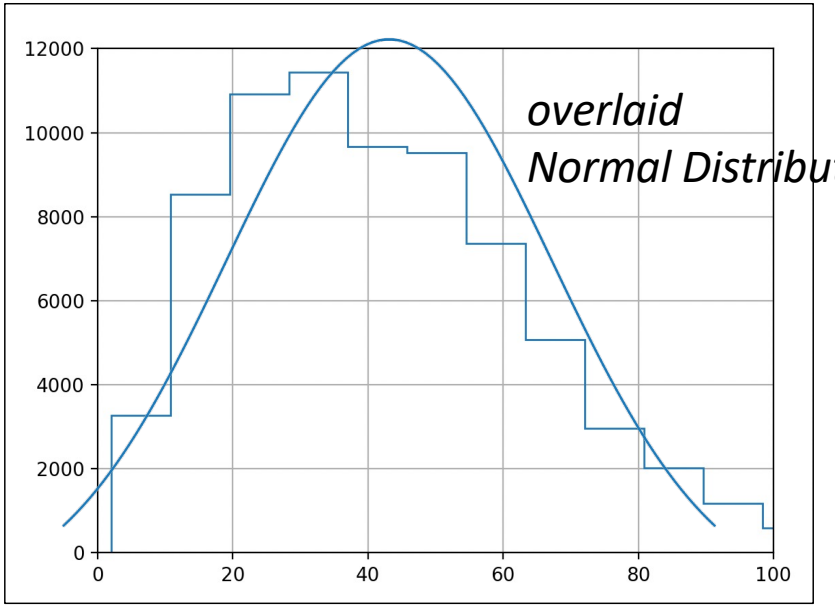
for a real number x.

The probability density

distribution use the `loc` and `scale` parameters. Specifically, `norm.pdf(x, loc, scale)` is

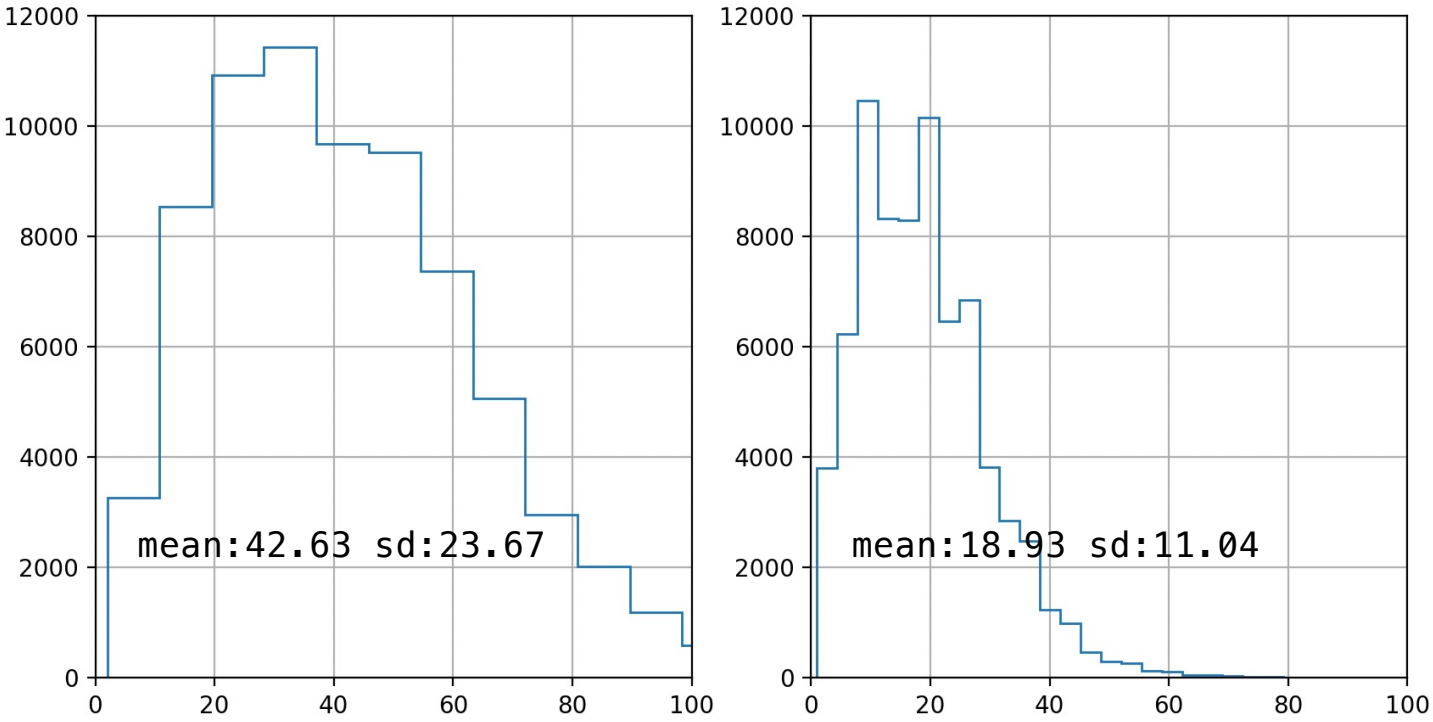
Distribution of Productions

```
>>> plt.hist(lrulec,histtype='step',bins=50)
>>> plt.xlim(0,100)
>>> plt.grid()
>>> plt.show()
```

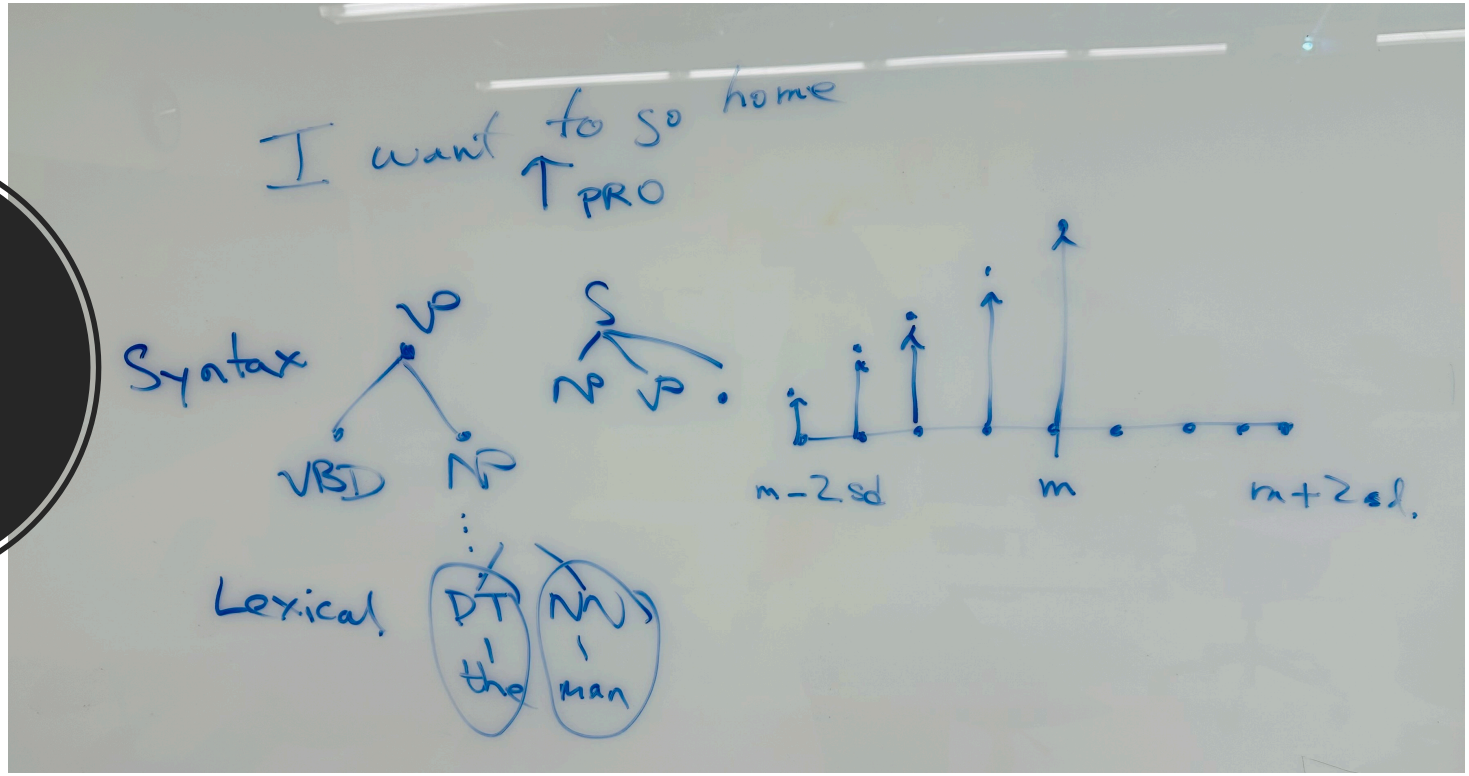


Distribution of Productions

with (*left*) and without (*right*) (word POS) nodes



Distribution of Productions



of Productions

Suppose list `rules` be all the rules in the `ptb`.

```
>>> rules = [p for t in trees for p in t.productions()]
>>> len(rules)
3131242
```

- Then let `srules` be all the (syntax), i.e. *nonlexical*, rules:

```
>>> srules = [r for r in rules if not(len(r.rhs()) == 1
 and isinstance(r.rhs()[0], str)]
>>> len(srules)
1390347
```

of Productions

```
>>> fd = nltk.FreqDist(srules)
>>> fd
FreqDist({PP -> IN NP: 78040, S -> NP-SBJ VP: 63335, NP
-> DT NN: 40876, NP-SBJ -> -NONE-: 39712, NP -> NP PP:
35819, NP-SBJ -> PRP: 31272, S -> NP-SBJ VP .: 24467, VP
-> TO VP: 21899, NP -> NN: 20798, NP -> -NONE-: 20312,
...})
>>> len(fd)
52134
>>> fd.N()
1390347
```

top-5 highlighted there: *interesting*!

Is this # cognitively plausible?

of Productions

- >>> fd.most_common(20)

```
1. [(PP -> IN NP, 78040),
2. (S -> NP-SBJ VP, 63335),
3. (NP -> DT NN, 40876),
4. (NP-SBJ -> -NONE-, 39712),
5. (NP -> NP PP, 35819),
6. (NP-SBJ -> PRP, 31272),
7. (S -> NP-SBJ VP ., 24467),
8. (VP -> TO VP, 21899),
9. (NP -> NN, 20798),
10.(NP -> -NONE-, 20312),
11.(PP-LOC -> IN NP, 18021),
12.(ADVP -> RB, 15449),
13.(NP -> DT JJ NN, 14898),
14.(NP -> NNS, 14875),
15.(VP -> MD VP, 13714),
16.(NP -> NNP, 12767),
17.(VP -> VB NP, 12730),
18.(PP-TMP -> IN NP, 11032),
19.(NP -> PRP, 10988),
20.(SBAR -> -NONE- S, 10774)]
```

of Productions

- Most syntax rules only occur once:

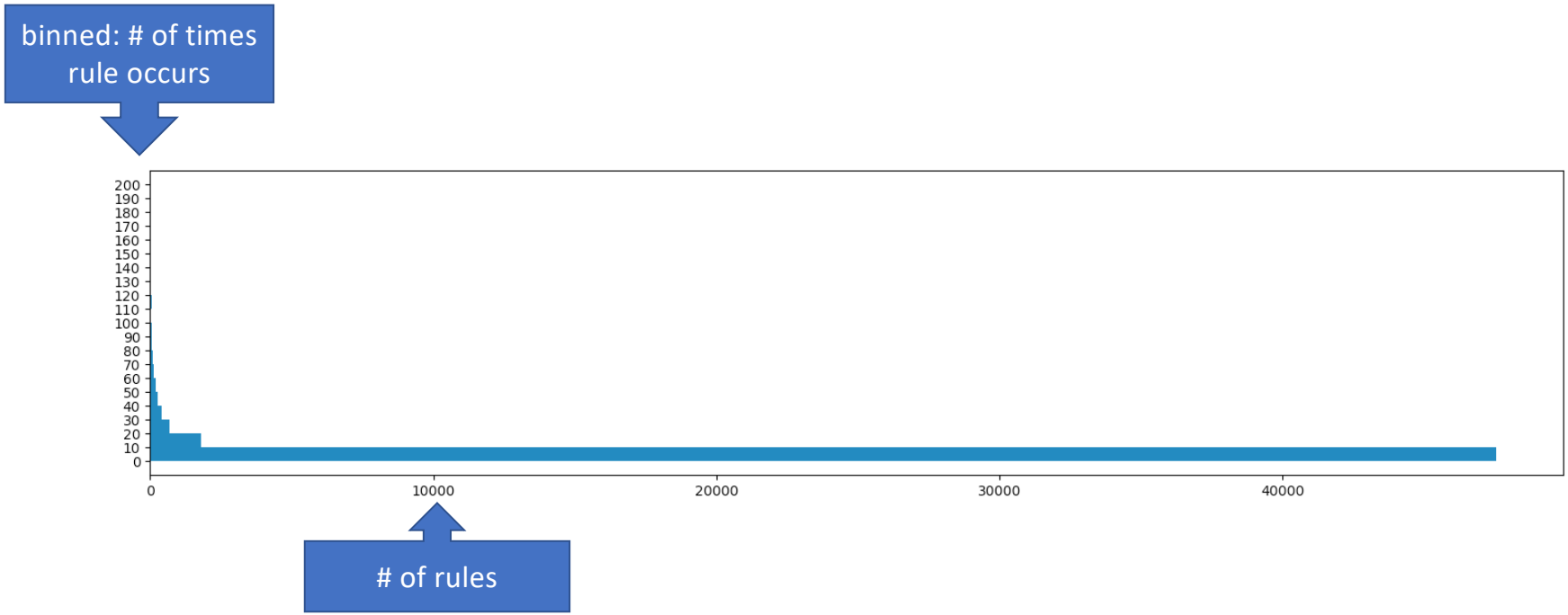
```
>>> len(fd)
52134
>>> fd.N()
1390347
>>> len(fd.hapaxes())
33631
```

hapaxes()

Return a list of all samples that occur once (hapax legomena)

How do they get learnt?

of Productions: histogram

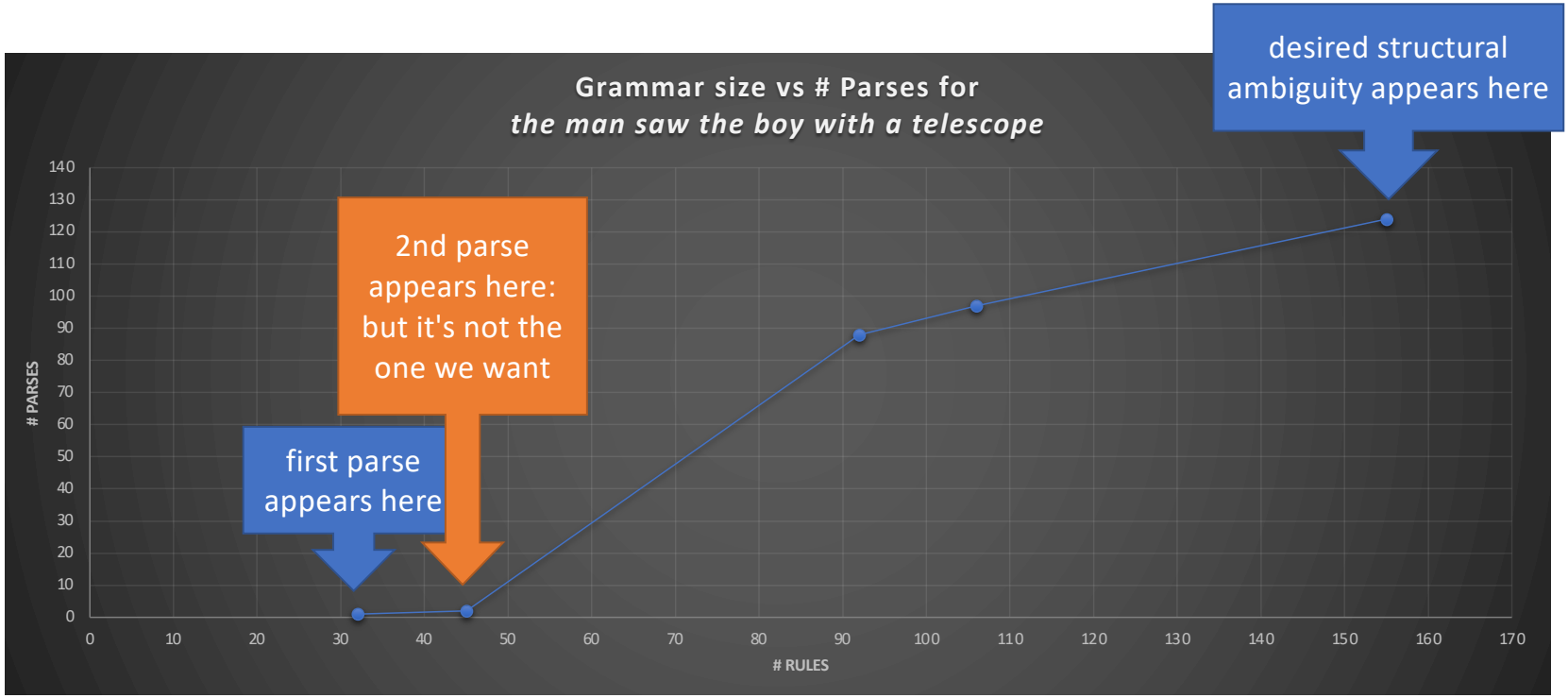


Smallest grammar for a sentence

- **Propose an Experiment:**
  - suppose we start with an empty CFG (no rules)
  - take PTB rules in order of frequency (*highest first*)
  - add them one at a time to the grammar
  - how many PTB rules before we can parse this sentence?*
    - *the man saw the boy with a telescope*
  - how many PTB rules do we need to obtain the structural ambiguity?

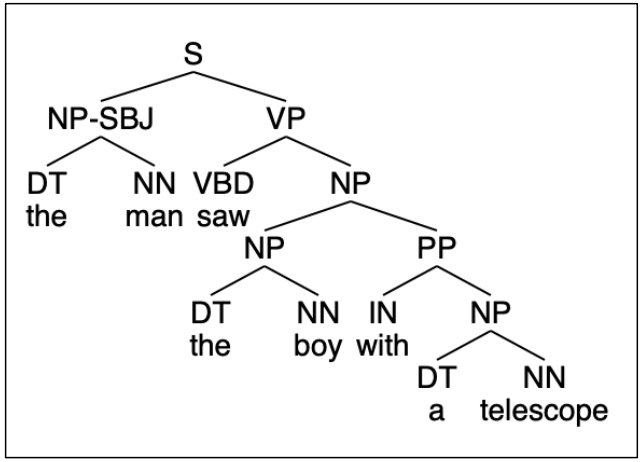
*some simplifications applied, explained later.

Smallest grammar for a sentence



Smallest grammar for a sentence

```
>>> find_scfg(s)
the DT 73202
man NN 886
saw VBD 329
the DT 73202
boy NN 191
with IN 7953
a DT 32606
telescope NN 3
(S
  (NP-SBJ (DT the) (NN man))
  (VP
    (VBD saw)
    (NP
      (NP (DT the) (NN boy))
      (PP (IN with) (NP (DT a)
(NN telescope))))))
Parses: 1,
# rules: 32,
# lexical rules: 7
```



Smallest grammar for a sentence

Parses: 1, # rules: 32, # lexical rules: 7

1. S -> NP-SBJ VP
2. PP -> IN NP
3. NP-SBJ -> NONE
4. NP -> DT NN
5. NP-SBJ -> PRP
6. NP -> NP PP
7. VP -> TO VP
8. NP -> NN
9. NP -> NONE
10. PP-LOC -> IN NP
11. ADVP -> RB
12. NP -> DT JJ NN
13. NP -> NNS
14. VP -> MD VP
15. SBAR -> WHNP S
16. NP -> NNP
17. VP -> VB NP
18. NP -> PRP
19. PP-TMP -> IN NP
20. SBAR -> NONE S
21. PP-CLR -> IN NP
22. NP -> NNP NNP
23. NP-SBJ -> DT NN
24. NP -> JJ NNS
25. NP -> NP SBAR
26. SBAR -> IN S
27. NP-SBJ -> NP PP
28. VP -> VBD VP
29. NP-SBJ -> NNP
30. VP -> VBD SBAR
31. ADVP-TMP -> RB
32. VP -> VBD NP
33. DT -> 'a'
34. NN -> 'telescope'
35. IN -> 'with'
36. DT -> 'the'
37. NN -> 'man'
38. NN -> 'boy'
39. VBD -> 'saw'

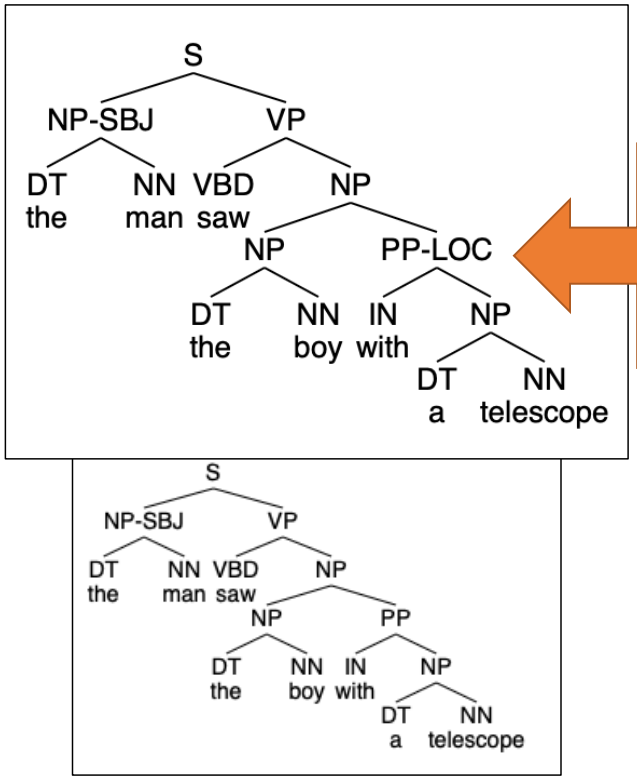
Smallest grammar for a sentence

Parses: 2, # rules: 45, # lexical rules: 7

1. S -> NP-SBJ VP
2. PP -> IN NP
3. NP-SBJ -> NONE
4. NP -> DT NN
5. NP-SBJ -> PRP
6. NP -> NP PP
7. VP -> TO VP
8. NP -> NN
9. NP -> NONE
10. PP-LOC -> IN NP
11. ADVP -> RB
12. NP -> DT JJ NN
13. NP -> NNS
14. VP -> MD VP
15. SBAR -> WHNP S
16. NP -> NNP
17. VP -> VB NP
18. NP -> PRP
19. PP-TMP -> IN NP
20. SBAR -> NONE S
21. PP-CLR -> IN NP
22. NP -> NNP NNP
23. NP-SBJ -> DT NN
24. NP -> JJ NNS
25. NP -> NP SBAR
26. SBAR -> IN S
27. NP-SBJ -> NP PP
28. VP -> VBD VP
29. NP-SBJ -> NNP
30. VP -> VBD SBAR
31. ADVP-TMP -> RB
32. VP -> VBD NP
33. PP -> TO NP
34. QP -> CD CD
35. S -> NONE
36. WHNP -> WDT
37. NP -> DT NNS
38. VP -> VBZ VP
39. VP -> VBG NP
40. NP-SBJ -> NNP NNP
41. NP -> NP CC NP
42. NP -> JJ NN
43. NP -> PRPS NN
44. VP -> VP CC VP
45. NP -> NP PP-LOC
46. NN -> 'man'
47. IN -> 'with'
48. DT -> 'a'
49. DT -> 'the'
50. NN -> 'boy'
51. VBD -> 'saw'
52. NN -> 'telescope'

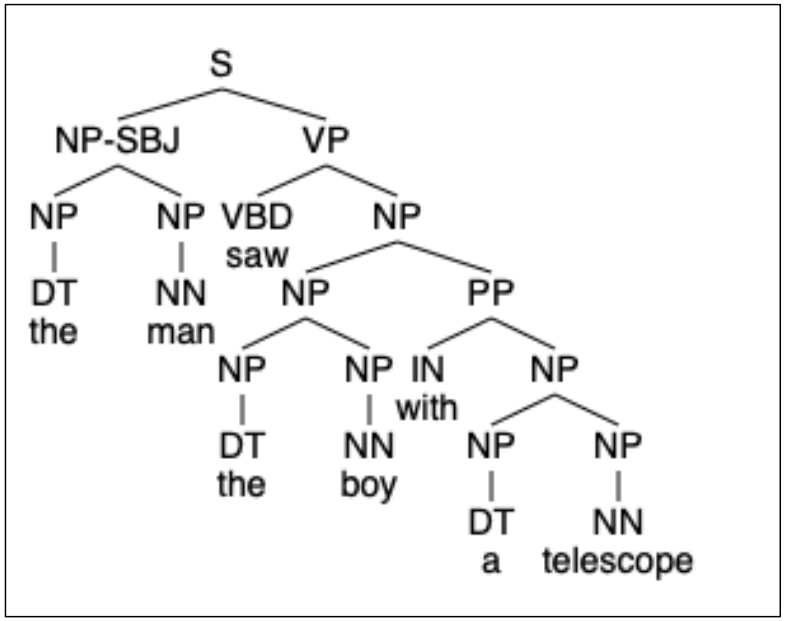
Smallest grammar for a sentence

```
(S
  (NP-SBJ (DT the) (NN man))
  (VP
    (VBD saw)
    (NP
      (NP (DT the) (NN boy))
      (PP-LOC (IN with) (NP (DT a) (NN
telescope))))))
(S
  (NP-SBJ (DT the) (NN man))
  (VP
    (VBD saw)
    (NP
      (NP (DT the) (NN boy))
      (PP (IN with) (NP (DT a) (NN
telescope))))))
Parses: 2, # rules: 45, # lexical rules: 7
```



not what you'd expect for the 2nd parse!

Smallest grammar for a sentence



- After two parses, it explodes combinatorially:
  - many more than 3 parses
  - *can you spot why*?

Smallest grammar for a sentence

Parses: 88, # rules: 92, # lexical rules: 7

1. S -> NP-SBJ VP
2. PP -> IN NP
3. NP-SBJ -> NONE
4. NP -> DT NN
5. NP-SBJ -> PRP
6. NP -> NP PP
7. VP -> TO VP
8. NP -> NN
9. NP -> NONE
10. PP-LOC -> IN NP
11. ADVP -> RB
12. NP -> DT JJ NN
13. NP -> NNS
14. VP -> MD VP
15. SBAR -> WHNP S
16. NP -> NNP
17. VP -> VB NP
18. NP -> PRP
19. PP-TMP -> IN NP
20. SBAR -> NONE S
21. PP-CLR -> IN NP
22. NP -> NNP NNP
23. NP-SBJ -> DT NN
24. NP -> JJ NNS
25. NP -> NP SBAR
26. SBAR -> IN S
27. NP-SBJ -> NP PP
28. VP -> VBD VP
29. NP-SBJ -> NNP
30. VP -> VBD SBAR
31. ADVP-TMP -> RB
32. VP -> VBD NP
33. PP -> TO NP
34. QP -> CD CD
35. S -> NONE
36. WHNP -> WDT
37. NP -> DT NNS
38. VP -> VBZ VP
39. VP -> VBG NP
40. NP-SBJ -> NNP NNP
41. NP -> NP CC NP
42. NP -> JJ NN
43. NP -> PRPS NN
44. VP -> VP CC VP
45. NP -> NP PP-LOC
46. NP -> NP NP
47. VP -> VBD S
48. NP -> QP NONE
49. NP -> DT NN NN
50. S-NOM -> NP-SBJ VP
51. PRT -> RP
52. VP -> VBP VP
53. WHNP -> WP
54. NP -> CD
55. NP -> NP VP
56. ADJP-PRD -> JJ
57. VP -> VB VP
58. NP -> NNP POS
59. S -> S CC S
60. WHADVP -> WRB
61. VP -> VBN NP
62. NP-SBJ -> NNS
63. NP -> NN NNS
64. SBAR-ADV -> IN S
65. NP-SBJ -> NP NP
66. S-ADV -> NP-SBJ VP
67. NP -> CD NNS
68. VP -> VBN NP PP
69. PP -> IN NP-LGS
70. VP -> VBZ NP
71. ADVP-MNR -> RB
72. PP-DIR -> TO NP
73. WHNP -> NONE
74. S-TPC -> NP-SBJ VP
75. NP-PRD -> NP PP
76. NP -> CD NN
77. NP -> NP NN
78. VP -> VBZ NP-PRD
79. NP -> NNP NNP NNP
80. VP -> VBZ S
81. VP -> VB S
82. ADVP-TMP -> NONE
83. S -> S-TPC NP-SBJ VP
84. NP -> DT NN POS
85. NP-SBJ -> NP SBAR
86. SBAR -> WHADVP S
87. NP -> PRPS NNS
88. NP-SBJ -> DT NNS
89. S -> PP NP-SBJ VP
90. PP -> IN S-NOM
91. PP-DIR -> IN NP
92. NP -> DT

always look at the last rule added!

93. IN -> 'with'
94. DT -> 'a'
95. VBD -> 'saw'
96. DT -> 'the'
97. NN -> 'boy'
98. NN -> 'man'
99. NN -> 'telescope'

Smallest grammar for a sentence

Parses: 106, # rules: 97, # lexical rules: 7

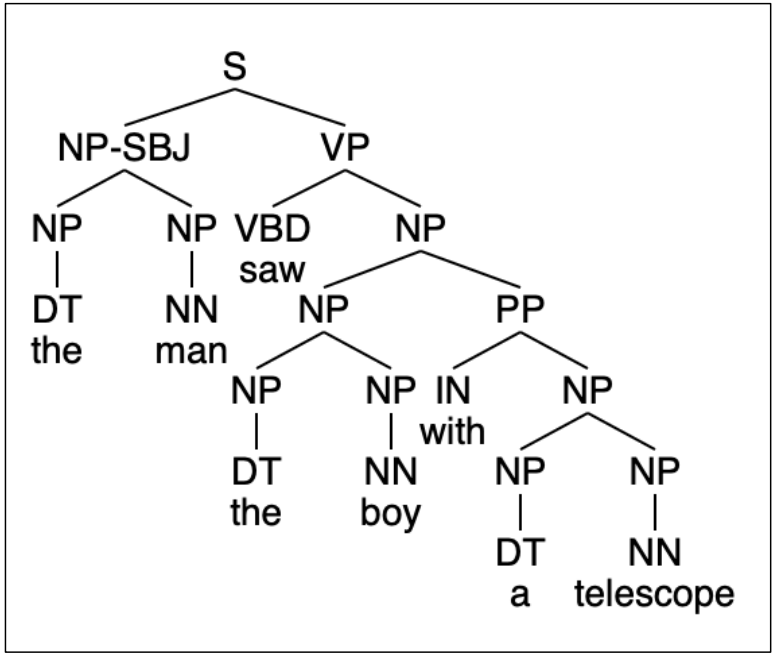
```
S -> NP-SBJ VP
PP -> IN NP
NP-SBJ -> NONE
NP -> DT NN
NP-SBJ -> PRP
NP -> NP PP
VP -> TO VP
NP -> NN
NP -> NONE
PP-LOC -> IN NP
ADVP -> RB
NP -> DT JJ NN
NP -> NNS
VP -> MD VP
SBAR -> WHNP S
NP -> NNP
VP -> VB NP
NP -> PRP
PP-TMP -> IN NP
SBAR -> NONE S
PP-CLR -> IN NP
NP -> NNP NNP
NP-SBJ -> DT NN
NP -> JJ NNS
NP -> NP SBAR
SBAR -> IN S
NP-SBJ -> NP PP
VP -> VBD VP
NP-SBJ -> NNP
VP -> VBD SBAR
ADVP-TMP -> RB
VP -> VBD NP
PP -> TO NP
QP -> CD CD
S -> NONE
WHNP -> WDT
NP -> DT NNS
VP -> VBZ VP
VP -> VBG NP
NP-SBJ -> NNP NNP
NP -> NP CC NP
NP -> JJ NN
NP -> PRPS NN
VP -> VP CC VP
NP -> NP PP-LOC
NP -> NP NP
VP -> VBD S
NP -> QP NONE
NP -> DT NN NN
S-NOM -> NP-SBJ VP
PRT -> RP
VP -> VBP VP
WHNP -> WP
NP -> CD
NP -> NP VP
ADJP-PRD -> JJ
VP -> VB VP
NP -> NNP POS
S -> S CC S
WHADVP -> WRB
VP -> VBN NP
NP-SBJ -> NNS
NP -> NN NNS
SBAR-ADV -> IN S
NP-SBJ -> NP NP
S-ADV -> NP-SBJ VP
NP -> CD NNS
VP -> VBN NP PP
PP -> IN NP-LGS
VP -> VBZ NP
ADVP-MNR -> RB
PP-DIR -> TO NP
WHNP -> NONE
S-TPC -> NP-SBJ VP
NP-PRD -> NP PP
NP -> CD NN
NP -> NP NN
VP -> VBZ NP-PRD
NP -> NNP NNP NNP
VP -> VBZ S
VP -> VB S
ADVP-TMP -> NONE
S -> S-TPC NP-SBJ VP
NP -> DT NN POS
NP-SBJ -> NP SBAR
SBAR -> WHADVP S
NP -> PRPS NNS
NP-SBJ -> DT NNS
S -> PP NP-SBJ VP
PP -> IN S-NOM
PP-DIR -> IN NP
NP -> DT
PP-CLR -> TO NP
NP -> NN NN
S -> NP-SBJ ADVP VP
VP -> VBP NP
VP -> VBD NP-PRD
IN -> 'with'
DT -> 'a'
VBD -> 'saw'
DT -> 'the'
NN -> 'boy'
NN -> 'man'
NN -> 'telescope'
```

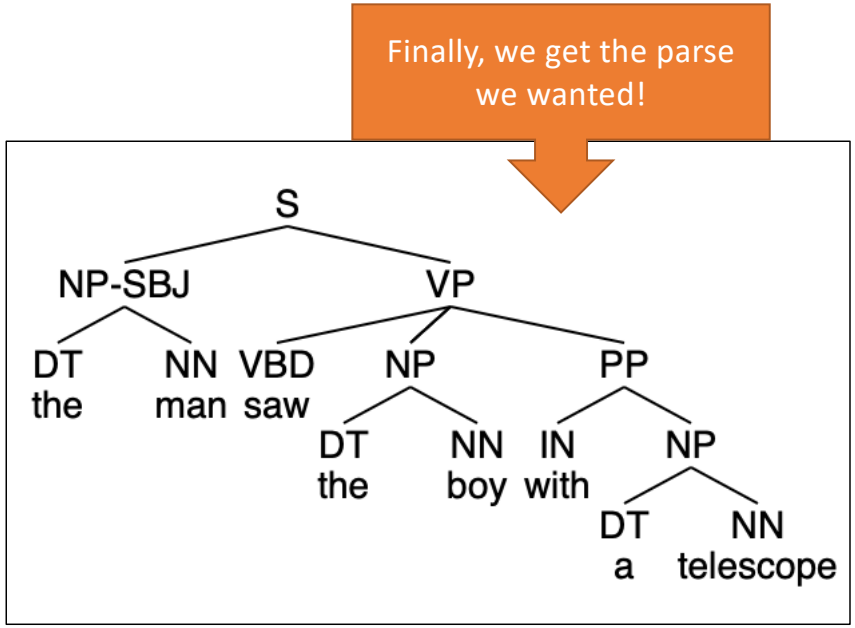
Smallest grammar for a sentence

Parses: 124, # rules: 155, # lexical rules: 7

S -> NP-SBJ VP
PP -> IN NP
NP-SBJ -> NONE
NP -> DT NN
NP-SBJ -> PRP
NP -> NP PP
VP -> TO VP
NP -> NN
NP -> NONE
PP-LOC -> IN NP
ADVP -> RB
NP -> DT JJ NN
NP -> NNS
VP -> MD VP
SBAR -> WHNP S
NP -> NNP
VP -> VB NP
NP -> PRP
PP-TMP -> IN NP
SBAR -> NONE S
PP-CLR -> IN NP
NP -> NNP NNP
NP-SBJ -> DT NN
NP -> JJ NNS
NP -> NP SBAR
SBAR -> IN S
NP-SBJ -> NP PP
VP -> VBD VP
NP-SBJ -> NNP
VP -> VBD SBAR
ADVP-TMP -> RB
VP -> VBD NP
PP -> TO NP
QP -> CD CD
S -> NONE
WHNP -> WDT
NP -> DT NNS
VP -> VBZ VP
VP -> VBG NP
NP-SBJ -> NNP NNP
NP -> NP CC NP
NP -> JJ NN
NP -> PRPS NN
VP -> VP CC VP
NP -> NP PP-LOC
NP -> NP NP
VP -> VBD S
NP -> QP NONE
NP -> DT NN NN
S-NOM -> NP-SBJ VP
PRT -> RP
VP -> VBP VP
WHNP -> WP
NP -> CD
NP -> NP VP
ADJP-PRD -> JJ
VP -> VB VP
NP -> NNP POS
S -> S CC S
WHADVP -> WRB
VP -> VBN NP
NP-SBJ -> NNS
NP -> NN NNS
SBAR-ADV -> IN S
NP-SBJ -> NP NP
S-ADV -> NP-SBJ VP
NP -> CD NNS
VP -> VBN NP PP
PP -> IN NP-LGS
VP -> VBZ NP
ADVP-MNR -> RB
PP-DIR -> TO NP
WHNP -> NONE
S-TPC -> NP-SBJ VP
NP-PRD -> NP PP
NP -> CD NN
NP -> NP NN
VP -> VBZ NP-PRD
NP -> NNP NNP NNP
VP -> VBZ S
VP -> VB S
ADVP-TMP -> NONE
S -> S-TPC NP-SBJ VP
NP -> DT NN POS
NP-SBJ -> NP SBAR
SBAR -> WHADVP S
NP -> PRPS NNS
NP-SBJ -> DT NNS
S -> PP NP-SBJ VP
PP -> IN S-NOM
PP-DIR -> IN NP
NP -> DT
PP-CLR -> TO NP
NP -> NN NN
S -> NP-SBJ ADVP VP
VP -> VBP NP
VP -> VBD NP-PRD
VP -> VBN S
VP -> VBZ SBAR
NP -> CD NN
NP-SBJ -> NN
NP -> DT NNP
S-PRP -> NP-SBJ VP
SBAR-TMP -> IN S
S -> CC NP-SBJ VP
NP-SBJ -> DT
NP -> DT JJ NNS
VP -> VBD ADJP-PRD
NP -> CD NONE
NP-SBJ -> EX
VP -> VBP SBAR
S -> PP-TMP NP-SBJ VP
SBAR-TMP -> WHADVP S
NP-ADV -> DT NN
PP -> IN NP
VP -> VB
NP -> DT ADJP NN
VP -> MD RB VP
ADJP -> RB JJ
VP -> VBZ ADJP-PRD
NP -> NNP NNP POS
S -> ADVP NP-SBJ VP
NP-SBJ -> DT JJ NN
SINV -> S-TPC VP NP-SBJ
VP -> VBG S
NP -> NP NP-ADV
S -> S S
VP -> VBN VP
NP -> PRPS JJ NN
NP -> DT JJ NN NN
NP-SBJ -> JJ NNS
S -> NP-SBJ ADVP-TMP VP
NP -> DT NNP NNP
NP -> DT NNP NN
NP -> QP NNS
VP -> VB NP PP
VP -> VB SBAR
ADJP -> JJ
VP -> VBD RB VP
S -> SBAR-ADV NP-SBJ VP
NP -> JJ NN NNS
S -> PP-LOC NP-SBJ VP
NP-SBJ -> NP PP-LOC
NP-SBJ -> PRPS NN
PP-PRD -> IN NP
NP -> DT JJ JJ NN
ADJP-PRD -> JJ PP
NP -> NP PP PP
VP -> VB ADJP-PRD
SBAR-PRP -> IN S
VP -> VB PP-CLR
VP -> VBD
VP -> VBP RB VP
NP-SBJ -> NN NNS
VP -> VBP S
VP -> VBD NP PP
DT -> 'a'
NN -> 'boy'
VBD -> 'saw'
DT -> 'the'
IN -> 'with'
NN -> 'man'
NN -> 'telescope'

Smallest grammar for a sentence





Smallest grammar for a sentence

plus a whole bunch of similar ones …

```
(S
  (NP-SBJ (DT the) (NN man))
  (VP
    (VBD saw)
    (NP (NP (DT the)) (NN boy))
    (PP (IN with) (NP (NP (DT a)) (NN telescope)))))
(S
  (NP-SBJ (DT the) (NN man))
  (VP
    (VBD saw)
    (NP (NP (DT the)) (NN boy))
    (PP (IN with) (NP (DT a) (NN telescope)))))
(S
  (NP-SBJ (DT the) (NN man))
  (VP
    (VBD saw)
    (NP (NP (DT the)) (NN boy))
    (PP (IN with) (NP (NP (DT a)) (NP (NN telescope))))))
(S
  (NP-SBJ (DT the) (NN man))
  (VP
    (VBD saw)
    (NP (DT the) (NN boy))
    (PP (IN with) (NP (NP (DT a)) (NN telescope)))))
(S
  (NP-SBJ (DT the) (NN man))
  (VP
    (VBD saw)
    (NP (DT the) (NN boy))
    (PP (IN with) (NP (DT a) (NN telescope)))))
```