1.4.1. Provide 10 random sentences generated from your script.

```
a president on the pickle under the sandwich in every delicious delicious pickle under every president on the chief of st
aff wanted every perplexed president in a sandwich in the chief of staff on the pickle in a delicious chief of staff with
 every sandwich under a chief of staff on a pickle with the pickle with a delicious chief of staff under every chief of s
taff on the chief of staff on a delicious chief of staff in a pickle under a pickle with every sandwich under the preside
nt in the chief of staff in a pickle under every pickled floor with the president on every floor with every sandwich in e
very chief of staff under the president on a pickle in every sandwich !
```

```
is it true that a fine pickled president understood a perplexed floor ?
```

```
is it true that the president with every floor on every president in a floor with a president on every perplexed fine flo
or with a floor kissed every sandwich ?
```

```
is it true that a chief of staff ate every pickle under the sandwich ?
```

```
is it true that every chief of staff pickled every perplexed pickle ?
```

```
is it true that every fine chief of staff kissed a pickled delicious fine pickle with the floor with a president under ev
ery chief of staff on every chief of staff on every pickle on the chief of staff on the chief of staff under the floor in
 the chief of staff with every president with every chief of staff ?
```

```
the president on the floor with the sandwich with every sandwich in the pickle under every perplexed pickle in a sandwich
 on a chief of staff on every pickled floor on the president in a chief of staff in a floor in a pickle with the sandwich
 in the president in every floor in a floor on every chief of staff on a perplexed sandwich with a sandwich under every s
andwich on a delicious president under a pickle in a pickle on the perplexed floor with a floor under every floor with a
president in every president in the floor in the chief of staff with a pickle on every chief of staff on a floor on the f
loor in the chief of staff in a pickle with the perplexed floor in every sandwich with every sandwich with every floor in
 every pickle in the chief of staff in every president with every floor in the perplexed chief of staff on a pickle in th
e president with a president on every president on the pickle under the delicious pickled fine sandwich with a floor in t
he pickle under the president with every chief of staff pickled a president under every sandwich under every pickle in ev
ery sandwich on a pickle with the sandwich in every chief of staff with every floor !
```

```
is it true that a floor pickled every delicious pickle under every floor with the pickle on every pickle in the president
 under every delicious floor on every floor in every sandwich in every president with the pickle in the floor under the c
hief of staff under the perplexed president in a chief of staff on a sandwich with the floor in a pickle in a floor in a
floor in every delicious pickled pickle under the pickle in every sandwich with a chief of staff with every pickle in eve
ry sandwich on every chief of staff under a sandwich with a pickle under every president in every chief of staff with a p
ickle on every floor with every chief of staff under the chief of staff under a floor ?
```

```
every floor on every pickle in every fine pickled pickle pickled every chief of staff .
```

```
every president with a pickle with a sandwich on every sandwich on every pickle under the president in the president with
 the sandwich in every pickle under every chief of staff in a delicious president on the president under a chief of staff
 with every pickle in a sandwich in a delicious sandwich under the floor with every pickle under a chief of staff on the
pickle in every pickled floor on a chief of staff with every pickle on a pickle on a chief of staff on every delicious pi
ckle with the president in the president with the perplexed delicious chief of staff under a pickle under the floor with
every pickle on every pickle under the fine chief of staff on a pickle in the president with a president under the pickle
 under a perplexed sandwich on a fine pickle pickled every sandwich under every chief of staff with the perplexed fine pi
ckle in a pickle on the pickle on a sandwich in the chief of staff with a sandwich under the perplexed chief of staff on
a pickle in every floor with every president in the perplexed chief of staff in every delicious pickle in every sandwich
on the perplexed pickle on every pickle on a president under a sandwich with the pickle on every sandwich with a chief of
 staff in a chief of staff with a sandwich with the pickle in the president under the floor under every pickled pickle on
 every chief of staff ... ... ... ... ... ... ... ...
```

1.4.2. Provide 2 random sentences generated from your script, using --tree to show their derivations.

```
      ..
(ROOT is
      it
      true
      that
      (S (NP (Det a)
             (Noun chief
                   of
                   staff))
         (VP (Verb ate)
             (NP (NP (NP (NP (NP (NP (Det a)
                                     (Noun pickle))
                                 (PP (Prep on)
                                     (NP (Det the)
                                         (Noun (Adj pickled)
                                               (Noun floor)))))
                             (PP (Prep under)
                                 (NP (NP (NP (Det a)
                                             (Noun floor))
                                         (PP (Prep on)
                                             (NP (NP (NP (NP (Det a)
                                                             (Noun pickle))
                                                         (PP (Prep under)
                                                             (NP (Det the)
                                                                 (Noun chief
                                                                       of
                                                                       staff))))
                                                     (PP (Prep on)
                                                         (NP (Det every)
                                                             (Noun chief
                                                                   of
                                                                   staff))))
                                                 (PP (Prep under)
                                                     (NP (Det a)
                                                         (Noun sandwich))))))
                                     (PP (Prep under)
                                         (NP (Det a)
                                             (Noun pickle))))))
                         (PP (Prep with)
                             (NP (Det every)
                                 (Noun chief
                                       of
                                       staff))))
                     (PP (Prep on)
                         (NP (Det the)
                             (Noun president))))
                 (PP (Prep on)
                     (NP (Det the)
                         (Noun chief
                               of
                               staff))))))
      ?)
```

```
(ROOT (S (NP (Det the)
             (Noun sandwich))
         (VP (Verb wanted)
             (NP (Det every)
                 (Noun floor))))
      .)
```

1.4.3**. As in the previous question, but with a --max expansions of 5.**

```
is it true that the pickle ... ... ...
is it true that every chief of staff ... ... ...
... ... ... ... ... ...
every pickle ... ... ...
... ... ... ... ... ... ...
a ... ... ... ...
the chief of staff ... ... ...
is it true that a floor ... ... ...
is it true that the chief of staff ... ... ...
every ... ... ... ...
```

```
(ROOT (S (NP (NP (Det a)
                 (Noun ...))
             ...)
         ...)
      ...)
(ROOT is
      it
      true
      that
      (S (NP (Det a)
             (Noun (Adj ...)
                   ...))
         ...)
      ...)
```

2.1.1. Why does your program generate so many long sentences? Specifically, what grammar rule (or rules) is (or are) responsible and why? What is special about it/them?

Because there are some nonterminal symbols cause multi repetition. For example:

```
1 NP Det Noun
1 NP NP PP
1 PP Prep NP
1 Noun Adj Noun
```

2.1.2. The grammar allows multiple adjectives, as in the fine perplexed pickle. Why do your program's sentences do this so rarely? (Give a simple mathematical argument.)

Because following the rules below: $p(two\ adjective\ before\ the\ Noun/Noun) = \frac{1}{6} * \frac{1}{6} = \frac{1}{36}$

$$p(three\ adjective\ before\ the\ Noun/Noun) = \frac{1}{6} * \frac{1}{6} * \frac{1}{6} = \frac{1}{216}$$

$$p(m\ adjective\ before\ the\ Noun/Noun) = (\frac{1}{6})^m$$

Therefore, multiple adjectives are rare

```
1 Noun Adj Noun
1 Noun president
1 Noun sandwich
1 Noun pickle
1 Noun chief of staff
1 Noun floor
```

2.1.3. Which numbers must you modify to fix the problems in item 1 and item 2, making the sentences shorter and the adjectives more frequent?

Put these adjustments in a new grammar file named grammar2.gr. Check your answer by running your generator!

```
10 NP Det Noun
5 Noun Adj Noun
```

```
the pickle wanted a floor !
the delicious perplexed perplexed fine sandwich kissed the fine delicious floor !
```

The results are more shorter and have more adjectives

2.1.4. What other numeric adjustments can you make to grammar2.gr in order to favor more natural sets of sentences? Experiment. Explain the changes.

I'll change the number of

```
1    ROOT    S .
1    ROOT    S !
1    ROOT    is it true that S ?     # mixing terminals and nonterminals is ok.
```

to

```
4    ROOT    S .
2    ROOT    S !
1    ROOT    is it true that S ?     # mixing terminals and nonterminals is ok.
```

Since sentences with the declarative structure are much more common in our daily life.

Furthermore, increase the weight for "the", since phrases like "the president" and "the sandwich" is more common than "a president" or "a sandwich".

2.1.5. Provide 10 random sentences generated with the grammar2.gr.

```
the pickle kissed a delicious chief of staff .
is it true that the floor wanted the delicious pickle ?
a perplexed delicious delicious pickled delicious pickle kissed the pickled delicious sandwich .
a perplexed pickled pickled fine sandwich ate a perplexed chief of staff .
a sandwich wanted a pickled delicious floor with the floor .
a fine perplexed pickled sandwich ate a pickle .
every floor ate a sandwich .
the sandwich pickled a fine pickled delicious chief of staff under every delicious president !
is it true that every perplexed pickled sandwich kissed a delicious sandwich ?
every delicious pickled sandwich pickled the pickled floor under the fine pickled perplexed chief of staff !
```

2.1.9. Briefly discuss your modifications to the grammar.

- Separate the VP into “IntranVerb” and “tranVerb NP”

```
2	IntranVerb	sighed
2	IntranVerb	worked
2	tranVerb	thought
2	tranVerb	ate
2	tranVerb	wanted
2	tranVerb	kissed
2	tranVerb	understood
2	tranVerb	pickled
2	tranVerb	perplexed
```

- To generate sentences like 4, add “S→NP thought that S”
- To generate sentences like 5, add “S→it VP that S”
- To generate “very very”, add “Adj→Adv Adj” and “Adv→extremely” and “Adv→very”

```
1	Adj	Adv Adj	#the very very very perplexed president

1	Adv	very
1	Adv	extremely
```

- To generate conjunctions, add

```
1	NP	NP Conj NP	# Sally and the president
1	tranVerb	tranVerb Conj tranVerb	#wanted and ate a sandwich
1	IntranVerb	IntranVerb Conj IntranVerb

1	Conj	and
1	Conj	or
```

2.1.10. Provide 10 random sentences generated with grammar3.gr that illustrate your modifications.

```
(base) ➜  hw-grammar python3 randsent.py -g grammar3.gr -n 10
it wanted it .
the pickled pickled pickle under a fine pickled desk understood every proposal !
a perplexed desk or a proposal pickled and understood it under a sandwich .
it ate Sally that every president sighed .
Sally ate a floor .
is it true that Sally ate the delicious sandwich ?
it and it pickled it .
it thought that every sandwich thought it .
that a sandwich wanted a pickled chief of staff wanted the chief of staff !
that it understood Sally wanted every perplexed sandwich in Sally .
```

3.1.1(a) another deviation:

```
(ROOT (S (NP (NP (Det every)
                 (Noun sandwich))
             (PP (Prep with)
                 (NP (NP (Det a)
                         (Noun pickle))
                     (PP (Prep on)
                         (NP (Det the)
                             (Noun floor))))))
         (VP (Verb wanted)
             (NP (Det a)
                 (Noun president)))) .)
```

3.1.1(b) we must care about that. Because the meaning in different derivations is different. The first derivation means a sandwich on the floor, while the second one means a pickle on the floor

3.3.2.

Example 1: successfully resolve the original derivation

```
(ROOT (S (NP (Pronoun it))
         (tranVerb ate)
         that
         (S (NP (ProperNoun Sally))
            (VP (tranVerb understood)
                (NP (Det the)
                    (Noun (Adj pickled)
                          (Noun (Adj perplexed)
                                (Noun chief
                                      of
                                      staff)))))))
      .)
```

Example 2: it wanted sally with it and every sandwich or it with sally on sally under the sandwich that sally pickled the chief of staff.

In this sentence, there are tons of ambiguities. For example, for sally with it and every sandwich, can be interpreted as "sally and every sandwich" or "it and every sandwich"

```
(ROOT (S it
         (VP (tranVerb wanted)
             (NP (NP (ProperNoun Sally))
                 (PP (Prep with)
                     (NP (NP (Pronoun it))
                         (Conj and)
                         (NP (NP (NP (Det every)
                                     (Noun sandwich))
                                 (Conj or)
                                 (NP (NP (Pronoun it))
                                     (PP (Prep with)
                                         (NP (ProperNoun Sally)))))
                             (PP (Prep on)
                                 (NP (NP (ProperNoun Sally))
                                     (PP (Prep under)
                                         (NP (Det the)
                                             (Noun sandwich)))))))))))
         that
         (S (NP (ProperNoun Sally))
            (VP (tranVerb pickled)
                (NP (Det the)
                    (Noun chief
                          of
                          staff)))))
      .)
```

3.3.3. there are five ways to analyze the noun phrase below. There are three “prep” in the noun phrase: with on and under. The total ways are 1*2*3-1 = 5. Because there is an invalid permutation, which is when on the floor is used to modify every sandwich, under the chief of staff cannot modify a pickle

```
every sandwich with a pickle on the floor under the chief of staff
 (NP (NP (NP (Det every) (Noun sandwich)) (PP (Prep with) (NP (Det a) (Noun pickle)))) (PP (P
rep on) (NP (NP (Det the) (Noun floor)) (PP (Prep under) (NP (Det the) (Noun chief of staff))
))))
# number of parses = 5
```

3.3.4.
For grammar.py, the longer the sentence, the more parses. Besides, ambiguities always occur in noun phrase “NP”
For grammar3.py, ambiguities occur in either noun phrases and conjunctions words, such as “and” “or”.

Example 1, in grammar.py, s sentence with 7 “PP” structure. The number of parses is 429

```
(base) → hw-grammar python3 randsent.py -g grammar.gr -n 1 | ./parse -g grammar.gr -c | ./prettyprint
(ROOT (S (NP (NP (Det every)
                 (Noun sandwich))
             (PP (Prep under)
                 (NP (NP (Det a)
                         (Noun (Adj perplexed)
                               (Noun (Adj fine)
                                     (Noun (Adj fine)
                                           (Noun pickle)))))
                     (PP (Prep on)
                         (NP (NP (Det the)
                                 (Noun sandwich))
                             (PP (Prep with)
                                 (NP (NP (Det the)
                                         (Noun (Adj fine)
                                               (Noun president)))
                                     (PP (Prep under)
                                         (NP (NP (NP (NP (Det a)
                                                         (Noun floor))
                                                     (PP (Prep under)
                                                         (NP (Det the)
                                                             (Noun sandwich))))
                                                 (PP (Prep with)
                                                     (NP (Det every)
                                                         (Noun (Adj fine)
                                                               (Noun sandwich)))))
                                             (PP (Prep in)
                                                 (NP (Det a)
                                                     (Noun pickle)))))))))))
          (VP (Verb pickled)
              (NP (Det the)
                  (Noun chief
                        of
                        staff))))
      !))
# number of parses = 429
```

Example 2, in grammar3.py

```
(ROOT (S (NP (NP (Pronoun it))
             (PP (Prep under)
                 (NP (NP (Pronoun it))
                     (Conj or)
                     (NP (NP (Det every)
                             (Noun (Adj fine)
                                   (Noun pickle)))
                         (PP (Prep under)
                             (NP (Pronoun it)))))))
         (tranVerb pickled)
         that
         (S it
            (VP (tranVerb wanted)
                (NP (Det a)
                    (Noun president)))
            that
            (S (NP (NP (Det every)
                       (Noun (Adj perplexed)
                             (Noun chief
                                   of
                                   staff)))
                   (PP (Prep in)
                       (NP (ProperNoun Sally))))
               (VP (tranVerb understood)
                   (NP (NP (Pronoun it))
                       (PP (Prep with)
                           (NP (Det every)
                               (Noun chief
                                     of
                                     staff)))))))))
      .)
# number of parses = 5
```

3.3.5 (a)

- $p(best\_parse) = \frac{1}{3} * 1 * \frac{1}{2} * \frac{1}{3} * \frac{1}{6} * 1 * \frac{1}{5} * \frac{1}{2} * \frac{1}{3} * \frac{1}{6} = 5.144e^{-05}$
- $p(best\_parse) = p(sentence)$ because the best_parse is the only possible way to parse the sentence
- Because the best_parse is the only parse way, thus, given this sentence, the possibility of best_parse is equal to 1

3.3.5 (b) There are two possible parse methods for this sentence, and these two ways have the equal possibility. Because the possibility of choosing "NP→ Det Noun" and "NP→ NP PP" is equal.

```
1 → NP → Det Noun
1 → NP → NP PP
```

3.3.5 (c) $cross - entropy = -(\log(5.144e^{-05}) + \log(1.240e^{-09}))/18 = -((-14.246) + (-29.587))/18 = -(-43.833)/18 = 2.435$

3.3.5 (d)$perplexity = 2^{2.435} = 5.408$

3.3.5 (e)
p(sentence1) = 5.144e-05
p(sentence 2) = 0

Since the probability of generating sentence 2 is 0, the cross-entropy would be infinity. Therefore, the compression program cannot used to compress the sentence 2, because we would need infinity bits.

3.3.6 (a) We use grammar2 to generate a corpus containing 10000 sentences, with 103587 words. The cross-entropy of grammar2 is 2.203 bits

```
# cross-entropy = 2.203 bits = -(-228161.989 log-prob. / 103587 words)
```

3.3.6 (b) Similarly, generate 10000 sentences with 107061 words from grammar3, the cross-entropy of grammar3 is 2.500 bits

```
# cross-entropy = 2.500 bits = -(-267642.627 log-prob. / 107061 words)
```

Grammar3 has higher entropy than grammar2, because we add more sentence structure in grammar3. For example, we split the verb into transitive verb and intransitive verb. We also add a conjunction structure.

3.3.6 (c) When try to compute the entropy of grammar, we got Inf bits. Because grammar tends to generate sentences with "…". Since "…" didn't occur in grammar, thus, P(sentence)=0, and cross-entropy = Inf.

3.3.7. Generate a corpus with 10000 sentences from grammar2, then use grammar,grammar2 and grammar3 to compute the cross-entropy.
We find that cross-entropy for grammar2 = 2.199, while cross-entropy for grammar3 is 2.750 bits and for grammar = 2.531, and both are higher than grammar2 itself. Furthermore, we can see that the difference between grammar3 and grammar2 is bigger than grammar and grammar2. We are not surprised by that result, since we changed more on grammar3.

```
(base) ➜  hw-grammar cat corpus_grammar2 | ./parse -P -g grammar.gr
# cross-entropy = 2.531 bits = -(-262509.713 log-prob. / 103701 words)
```

```
(base) ➜  hw-grammar cat corpus_grammar2 | ./parse -P -g grammar2.gr
# cross-entropy = 2.199 bits = -(-227989.743 log-prob. / 103701 words)
```

```
(base) ➜  hw-grammar cat corpus_grammar2 | ./parse -P -g grammar3.gr
# cross-entropy = 2.750 bits = -(-285174.721 log-prob. / 103701 words)
```

4.1
(b) for the yes-no question, add

```
3 ROOT Aux S ?

1 Aux did
1 Aux will
1 Aux does
1 Aux can
```

(d) WH-word questions
1. We split the wh-words into three categories: wh-pronouns, wh-det and wh-adv
2. Wh-noun can work like the NP in a sentence, and wh-noun can be made by wh- pronouns, wh-det+noun and wh-det itself.
3. there are three wh-sentence structure in grammar4:

- wh-np vp ? this structure is identical to the declarative structure, except that the first noun phrase contains some wh-word
- wh-adv aux s? this structure is to implement sentence like "where did Sally eat the sandwich ?"
- wh-np aux nos? where nos is the sentence without objectives.

Add

```
1	wh-pronouns	who
#1	wh-pronouns	whom
#1	wh-pronouns	whose
1	wh-pronouns	which

1	wh-det	what
1	wh-det	which

1	wh-adv	where
1	wh-adv	when
1	wh-adv	how

1	wh-NP	wh-pronouns
1	wh-NP	wh-det
1	wh-NP	wh-det Noun    # what sandwich
```

and

```
3	ROOT	wh-NP VP ?    #who ate the sandwich
3	ROOT	wh-det Aux NOS ?     #what does the president think
3	ROOT	wh-adv Aux S ?      #where did Sally eat the sandwich ?
```