НАЦИОНАЛЬНЫЙ ИССЛЕДОВАТЕЛЬСКИЙ
УНИВЕРСИТЕТ

Tokenisation and word segmentation

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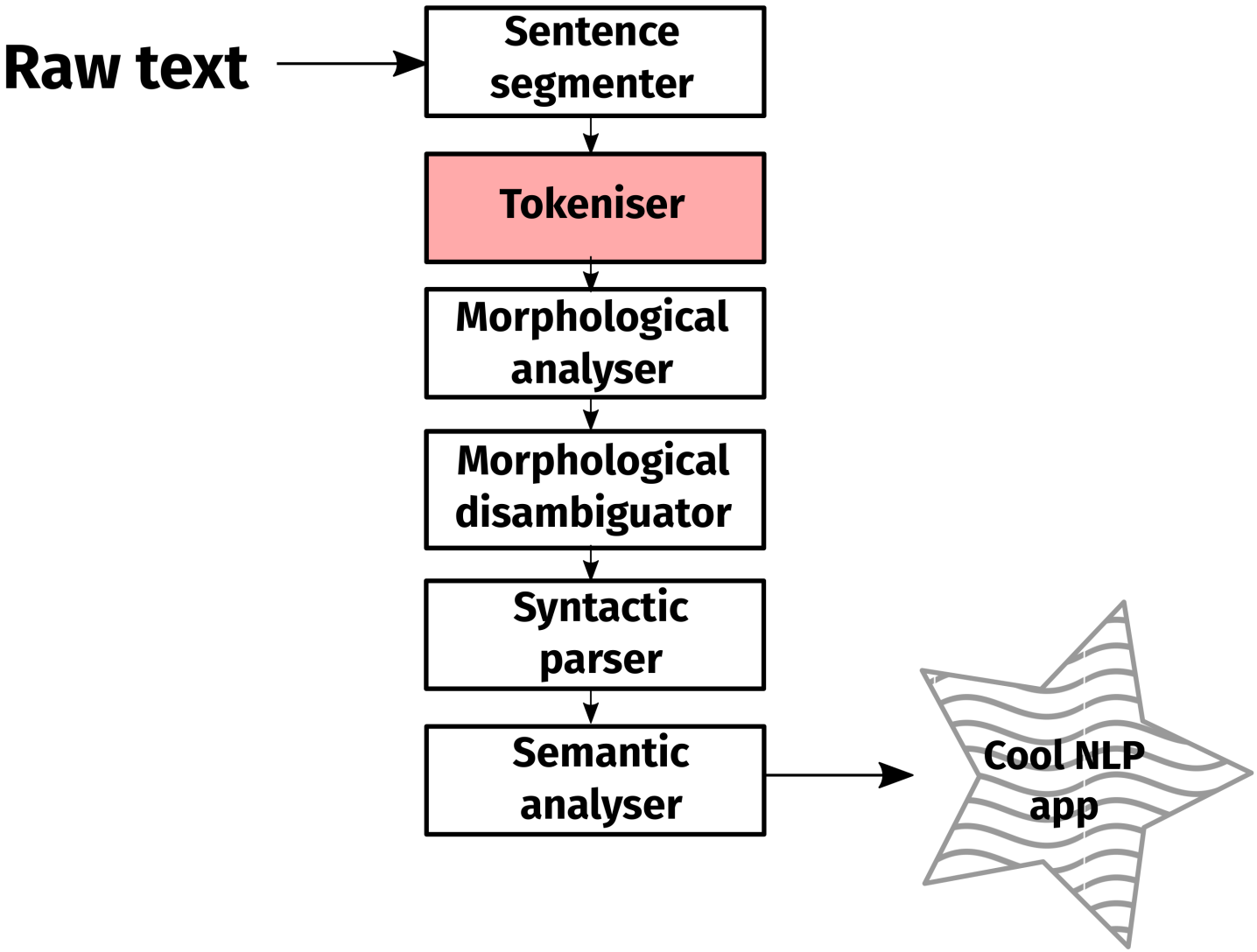
Pipeline


Raw text
Sentence segmenter
Tokeniser
Morphological analyser
Morphological disambiguator
Syntactic parser
Semantic analyser
Cool NLP app

Token separators

ARMA·VIRVMQVE·CANO·TROIAE·QVI·PRIMVS·AB·ORIS
ITALIAM·FATO·PROFVGVS·LAVINIAQVE·VENIT
LITORA·MVLTVM·ILLE·ET·TERRIS·IACTATVS·ET·ALTO
VI·SVPERVM·SAEVAE·MEMOREM·IVNONIS·OB·IRAM

- Peoplecangenerallyreadsentencesevenifthereisnowhitespace, but:
  - The vast majority of languages use some kind of whitespace-based word/token separator

But what is a token?

Some questions:

- Multiword expressions
  - *только что* or *только·что* ?
- Named-entities
  - *Нижный Новгород* or *Нижный·Новгород* ?
- Numeral expressions
  - *150 000,0* or *150·000,0*

And how about abbreviations:

- *Гипотеза была выдвинута Каролем Борсуком в 1933 г.*
  - Is there one ". here or two?
- *В 1933 г. гипотеза была выдвинута Каролем Борсуком.*
  - And here?

More questions

Clitics:

- Romance: *explicándoselo* [explicándo se lo], *j'ai* [j' ai]
- Germanic: *don't* [do n't], *I'm* [I 'm], *Nastya's* [Nastya 's]
- Slavic: *mógłbym* [mógł bym], *razumeću* [razume ću]
- Finnic: *voisiko* [voisi ko]
- Turkic: *чыгачакмы* [чыгачак мы]

Can be ambiguous:

- Nastya's cool $\rightarrow$ Nastya is
- Nastya's broke the record again $\rightarrow$ Nastya has
- Nastya's cat is cute $\rightarrow$ Nastya's

Is resolving this the job of a tokeniser ?

Tasks

The ideal tokenisation may depend on the task.[1]

- Russian–Arabic MT:
  - Split off clitics[2]
- Sentiment analysis:
  - Definitely want emoticons to be tokenised as a single unit ;)

[1] And also on the language (pair)!

[2] Zalmout and Habash (2017) “Optimizing Tokenization Choice for Machine Translation across Multiple Target Languages”

A simple approach

```
1  import sys, re
2
3  abbr = ['etc.', 'e.g.', 'i.e.']
4
5  def tokenise(line, abbr):
6      line = re.sub(r'([\(\)"?:!;])', r' \g<1> ', line)
7      line = re.sub(r'([^0-9]),', r'\g<1> ,', line)
8      line = re.sub(r',([^0-9])', r', \g<1>', line)
9      line = re.sub(r' +', ' ', line[:-1])
10
11     output = []
12     for token in line.split(' '):
13         if token[-1] == '.' and token not in abbr:
14             token = token[:-1] + ' .'
15         output.append(token)
16
17     return ' '.join(output)
18
19 line = sys.stdin.readline()
20 while line != '':
21     print(tokenise(line.strip('\n'), abbr))
22     line = sys.stdin.readline()
```

Split off always-separating punctuation [6]

A simple approach

```
1  import sys, re
2
3  abbr = ['etc.', 'e.g.', 'i.e.']
4
5  def tokenise(line, abbr):
6      line = re.sub(r'([\(\)"?:!;])', r' \g<1> ', line)
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19 line = sys.stdin.readline()
20 while line != '':
21     print(tokenise(line.strip('\n'), abbr))
22     line = sys.stdin.readline()
```

Split off commas not part of numeral expressions [7,8]

A simple approach

```
1  import sys, re
2
3  abbr = ['etc.', 'e.g.', 'i.e.']
4
5  def tokenise(line, abbr):
6      line = re.sub(r'([\(\)"?:!;])', r' \g<1> ', line)
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22     line = sys.stdin.readline()
```

Collapse multiple spaces [9]

A simple approach

```
1  import sys, re
2
3  abbr = ['etc.', 'e.g.', 'i.e.']
4
5  def tokenise(line, abbr):
6      line = re.sub(r'([\(\)"?:!;])', r' \g<1> ', line)
7      line = re.sub(r'([^0-9]),', r'\g<1> ,', line)
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14             token = token[:-1] + ' .'
15         output.append(token)
16
17     return ' '.join(output)
18
19 line = sys.stdin.readline()
20 while line != '':
21     print(tokenise(line.strip('\n'), abbr))
22     line = sys.stdin.readline()
```

Split of full stops not part of abbreviations [12–14]

Caveats

- Time and numeral expressions:
  - Let's meet at 17**:**45
- Proper names:
  - I'm surprised that Yahoo**!** are still solvent
  - Therapy**?** is one of the best bands from Northern Ireland
- Emoticons:
  - haters gonna hate **;____;**

Machine-learning approaches

Example:

В 1933 г. гипотеза была выдвинута Каролем Борсуком.

В	1	9	3	3	г	.	г	и	п	о	т	е	з	а	…
+	-	-	-	+	-	+	-	-	-	-	-	-	-	+	…

Two classes:

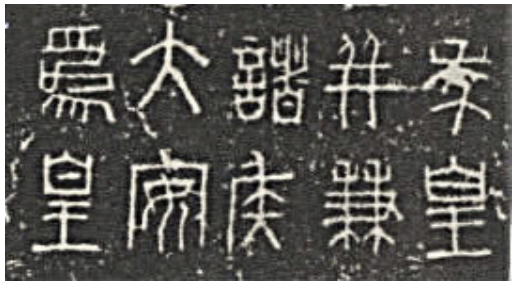
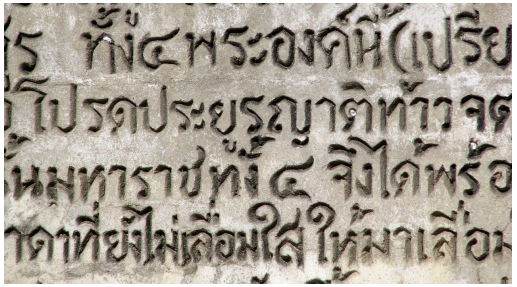
- (+) Token boundary follows
- (-) No boundary

Process:[3]

- Read through the sentence character by character
- Classify each character into ‘token boundary or not?’

[3] Straka, Hajič and Straková (2016) “UDPipe: Trainable Pipeline for Processing CoNLL-U Files Performing Tokenization, Morphological Analysis, POS Tagging and Parsing”.

Space-free languages

- Some languages are written without spaces
- Tokenisation more difficult — space is a strong signal
- Issue of ambiguity — more than one possible interpretation
- A number of algorithms available

Ambiguity

- Many analyses for each sequence
- How do we choose the correct one(s) ?

Graphics by Graham Neubig (NAIST)

(A tale of) two algorithms

Maxmatch:

- Rule-based algorithm
  - Requires some kind of dictionary — from wordlist or corpus

Graph-based:

- Statistical algorithm
  - Requires pre-segmented corpus

Maxmatch algorithm

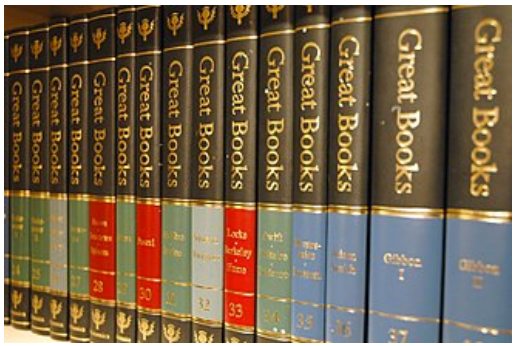
```
function MaxMatch(sentence, dictionary) returns word sequence W

    if sentence is empty
        return empty list
    for i ← length(sentence) downto 1
        firstword = first i chars of sentence
        remainder = rest of sentence
        if InDictionary(firstword, dictionary)
            return list(firstword, MaxMatch(remainder,dictionary) )

    # no word was found, so make a one-character word
    firstword = first char of sentence
    remainder = rest of sentence
    return list(firstword, MaxMatch(remainder,dictionary) )
```

- Start at beginning of string
- Iteratively look up the longest word in the dictionary
- If no word is found, output a single character

Caveats

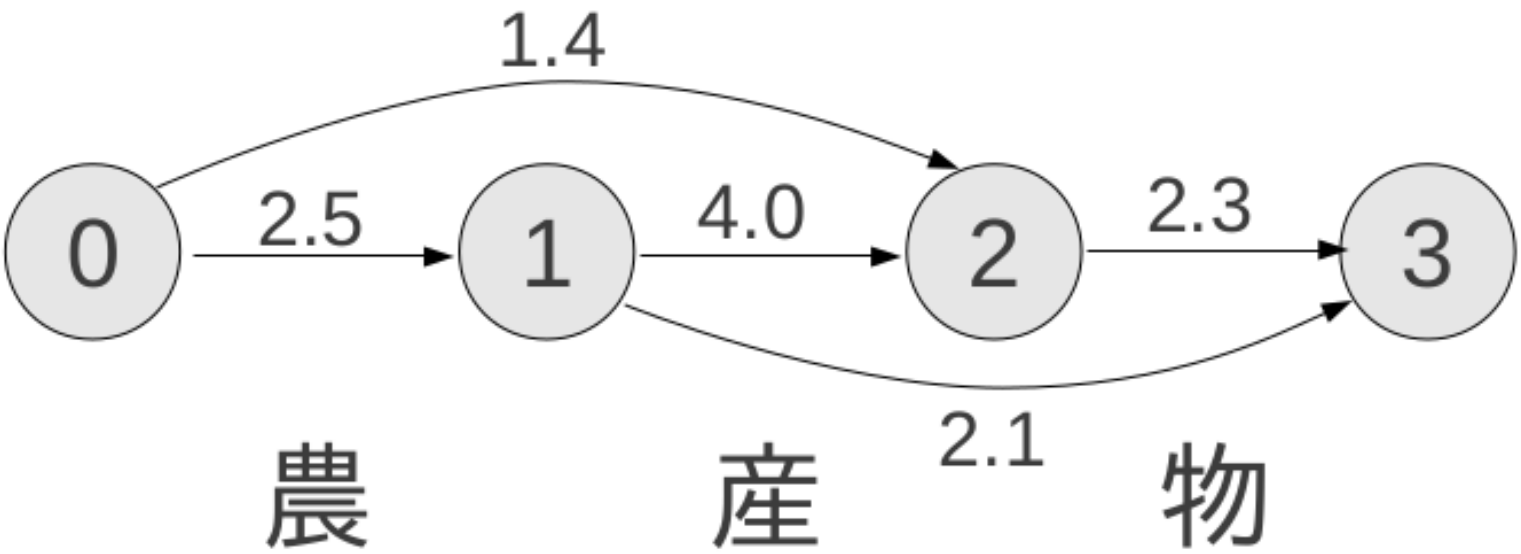



wecanonlyseeashortdistanceahead
we canon l y see ash ort distance ahead

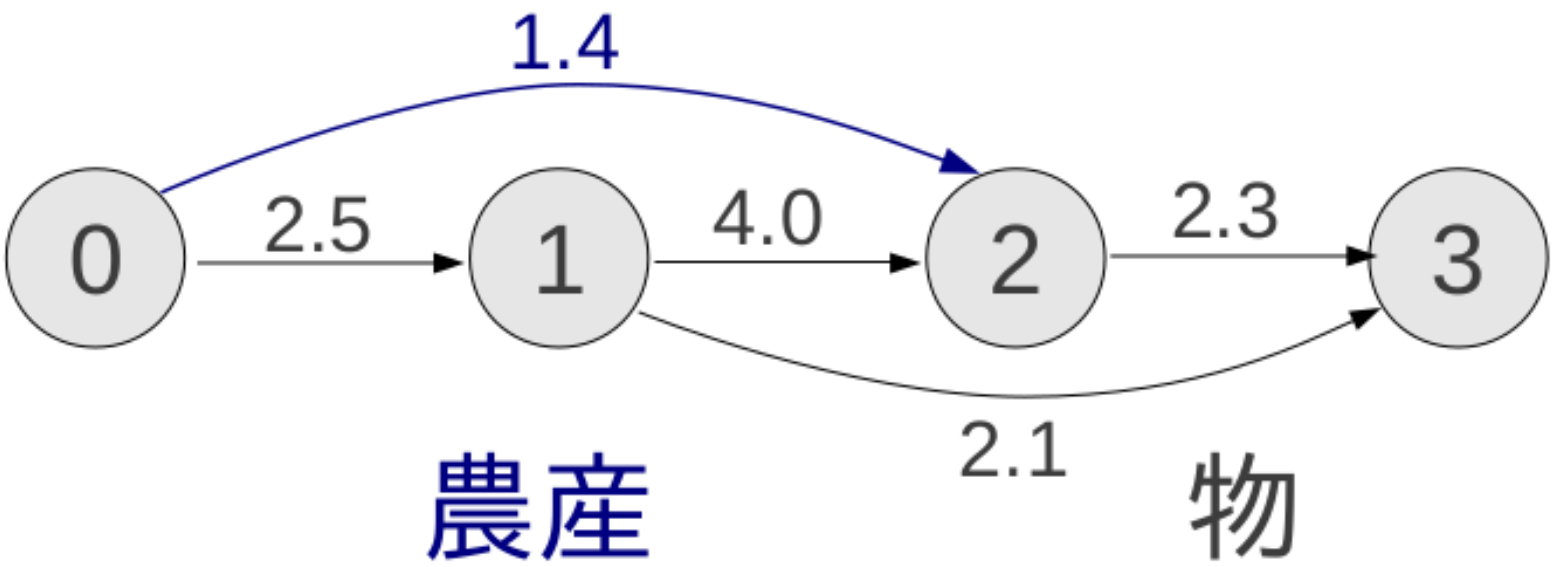
– Alan Turing

- Works pretty well for some languages (e.g. Chinese)
- Not so great for others
- Why? Length of words

A graph-based approach

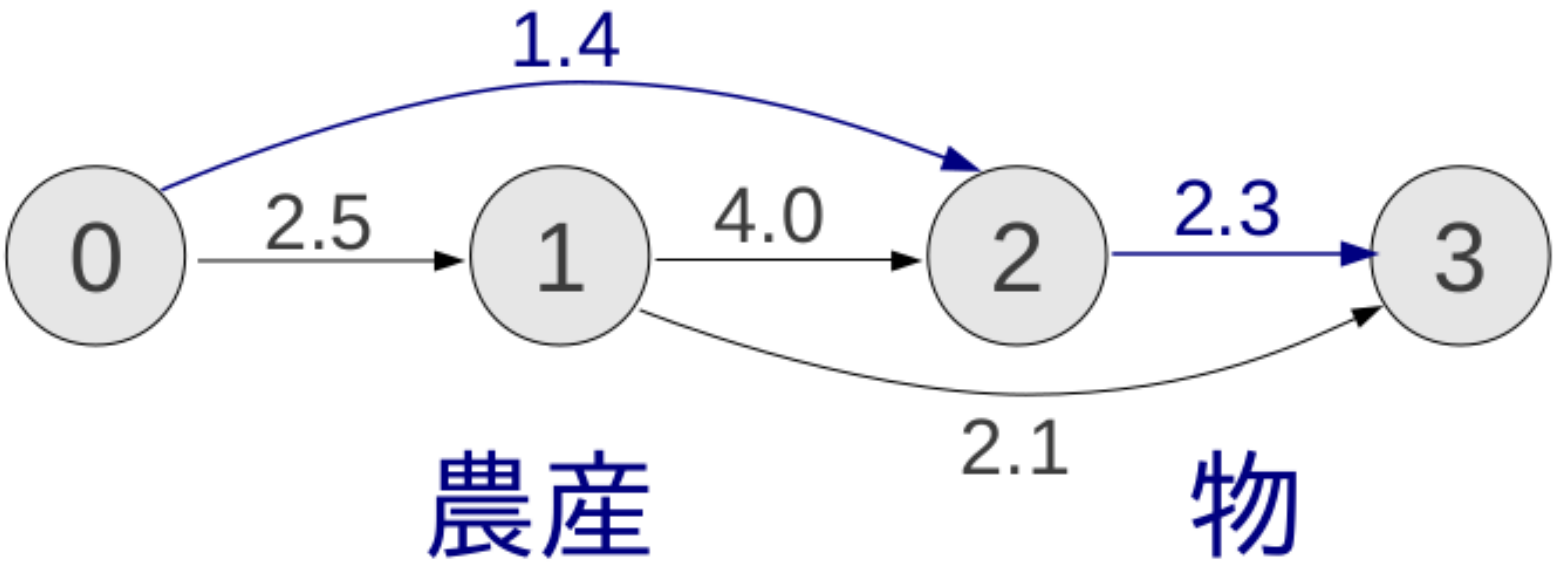


A graph-based approach



- Each edge is a word (segmentation decision)
- Each edge weight is a unigram probability

A graph-based approach



- Each path is a segmentation
- The path weight is the unigram probability of the sentence

Language model

P(農産　物　価格　安定　法)= $4.12*10^{-23}$

P(農産　物価　格安　定法) = $3.53*10^{-24}$

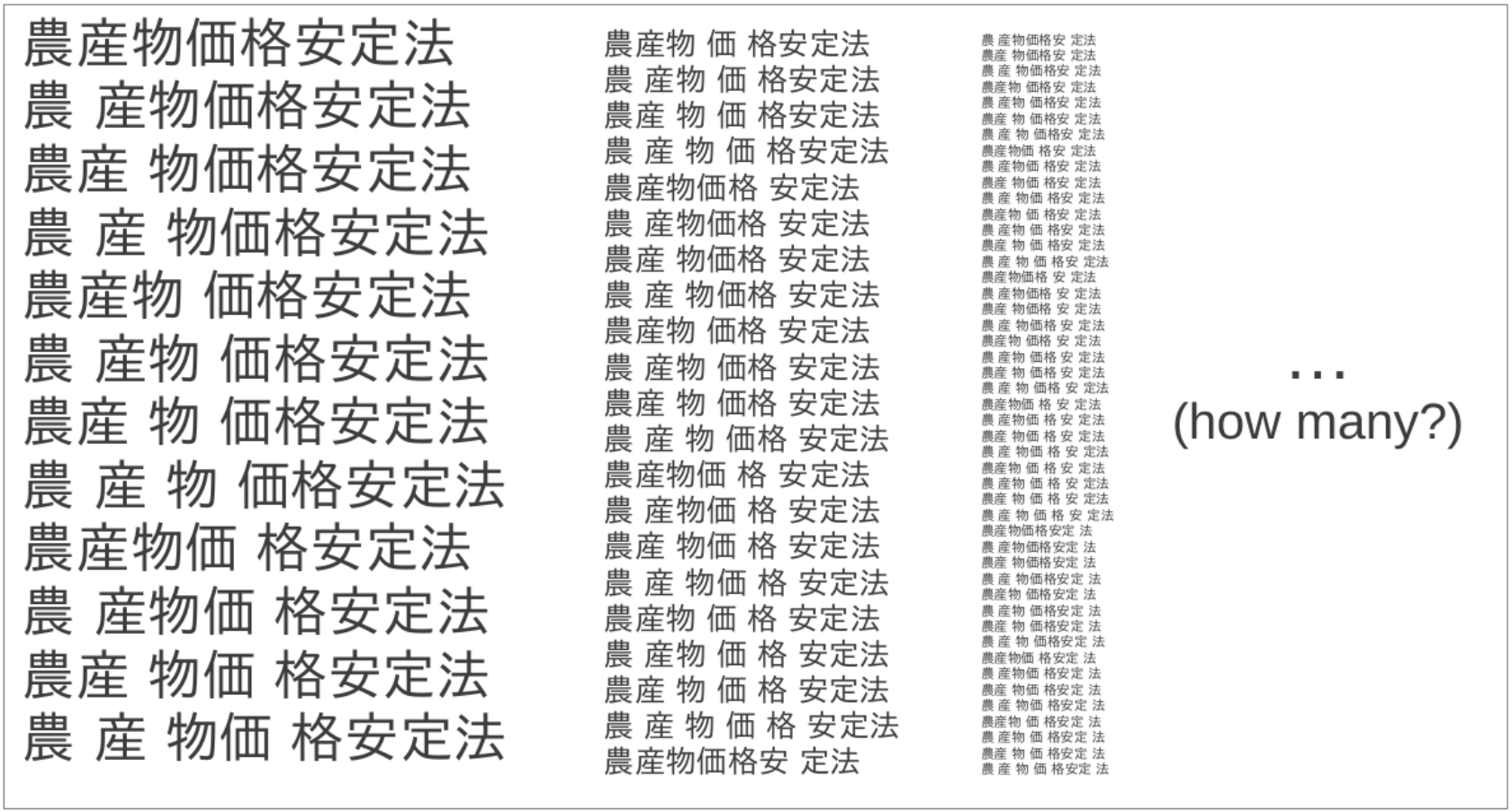
P(農産　物　価　格安　定法)= $6.53*10^{-25}$

P(農産　物　価格　安　定法)= $6.53*10^{-27}$

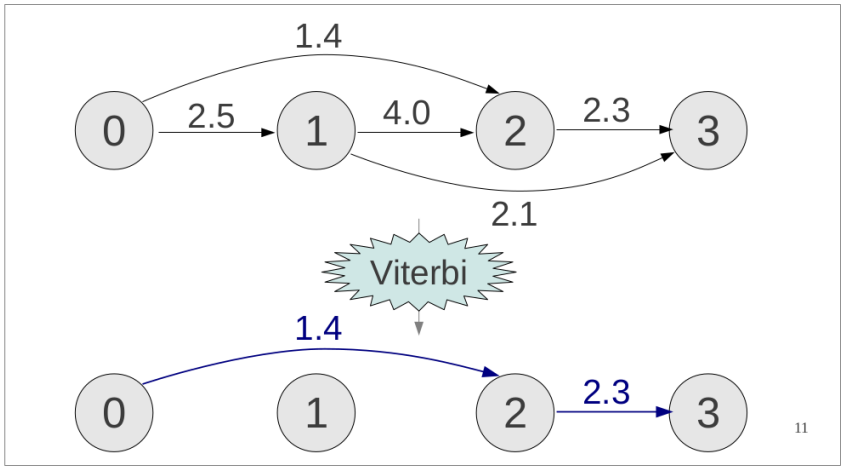
...

- Language model to choose sequence with highest probability
- Requires an existing tokenised corpus
- Maximum likelihood estimation (MLE):
  - Probability of a word: frequency / number of tokens in corpus

Combinatorial explosion



Finding the best segmentation



Viterbi algorithm:

- Forward step:
  - Search the graph left-to-right, picking the highest prob arc at each step,
  - leaving a pointer to the previously visited node
- Backward step:
  - Follow the pointers back to read off the path

[Algorithm covered in Lecture 3 *Morphological disambiguation*.]

Unknown words

What to do with out-of-vocabulary (OOV) items?

Smoothing:

- Add-one smoothing[4], basically just add 1 to every count
  - Assigns too much probability mass to unknown words
- Use the Good-Turing method (see Manning and Schütze, p.212)

[4] If you do this, avoid a man called Ken Church.

A note on encodings

Watch out for characters other than space (U+0020):

- Non-breaking spaces (U+2060, U+FEFF, …)
- Soft-hyphen (U+00AD)
- En quad (U+2000)
- En space (U+2002)

Plus 20 or so other characters.

Formats

Extra-spaces format:

```
Крайняя западная точка расположена в районе Фленсбурга (9°10′ в.д.).
                                ↓
Крайняя западная точка расположена в районе Фленсбурга ( 9°10′ в.д. ) .
```

- Widely used
- Basically just add in (extra) spaces to indicate tokenisation
- Easy to process
- Loses original text

Formats

CoNLL-U:

```
# text = Крайняя западная точка расположена в районе Фленсбурга (9°10′ в.д.).
1     Крайняя       _   _   _   _   _   _   _   _
2     западная      _   _   _   _   _   _   _   _
3     точка         _   _   _   _   _   _   _   _
4     расположена   _   _   _   _   _   _   _   _
5     в             _   _   _   _   _   _   _   _
6     районе        _   _   _   _   _   _   _   _
7     Фленсбурга    _   _   _   _   _   _   _   _
8     (             _   _   _   _   _   _   _   SpaceAfter=No
9     9°10′         _   _   _   _   _   _   _   _
10    в.д.          _   _   _   _   _   _   _   SpaceAfter=No
11    )             _   _   _   _   _   _   _   SpaceAfter=No
12    .             _   _   _   _   _   _   _   _
```

- More complex to process
- Original text can be reconstructed
- universaldependencies.org/format.html

Evaluation

Most common evaluation method is Word Error Rate (WER):

- Number of edits divided by number of tokens in the reference
  - Edits: insertions (I), deletions (D), substitutions (S)
- Implemented with Levenshtein distance

wecanonlyseeashortdistanceahead

```
REF: we can   only   see a   short distance ahead
HYP: we canon l    y see ash ort   distance ahead
EVA:    S     S    I     S   S
```

WER: $\frac{5}{8} = 62.5\%$

Practical

Implement the `maxmatch` algorithm and test it on Japanese:

- Extract surface form dictionary from the training corpus
- Run the algorithm with the dictionary on the test corpus
- Write script to calculate WER for the segmentation.
  - Feel free to use a library or existing code for this

https://github.com/UniversalDependencies/UD_Japanese-GSD