

EDAN20

Language Technology

<http://cs.lth.se/edan20/>
Chapter 2: Corpus Processing Tools

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Corpora

A corpus is a collection of texts (written or spoken) or speech
Corpora are balanced from different sources: news, novels, etc.

| | English | French | German |
|---|--|--|---|
| Most frequent words in a collection of contemporary running texts | <i>the</i> <i>of</i> <i>to</i> <i>in</i> <i>and</i> | <i>de</i> <i>le</i> (article) <i>la</i> (article) <i>et</i> <i>les</i> | <i>der</i> <i>die</i> <i>und</i> <i>in</i> <i>des</i> |
| Most frequent words in Genesis | <i>and</i> <i>the</i> <i>of</i> <i>his</i> <i>he</i> | <i>et</i> <i>de</i> <i>la</i> <i>à</i> <i>il</i> | <i>und</i> <i>die</i> <i>der</i> <i>da</i> <i>er</i> |



Characteristics of Current Corpora

Big: The Bank of English (Collins and U Birmingham) has more than 500 million words

Available in many languages

Easy to collect: The web is the largest corpus ever built and within the reach of a mouse click

Parallel: same text in two languages: English/French (Canadian Hansards), European parliament (23 languages)

Annotated with part-of-speech or manually parsed (treebanks):

- Characteristics/N of/PREP Current/ADJ Corpora/N
- (NP (NP Characteristics) (PP of (NP Current Corpora)))



Lexicography

Writing dictionaries

Dictionaries for language learners should be build on real usage

- *They're just trying to score **brownie points** with politicians*
- *The boss is pleased – that's another **brownie point***

Bank of English: *brownie point* (6 occs) *brownie points* (76 occs)

Extensive use of corpora to:

- Find **concordances** and cite real examples
- Extract **collocations** and describe frequent pairs of words



Concordances

A word and its context:

| Language | Concordances |
|----------|---|
| English | s beginning of miracles did Je n they saw the miracles which n can do these miracles that t ain the second miracle that Je e they saw his miracles which |
| French | le premier des miracles que fi i dirent: Quel miracle nous mo om, voyant les miracles qu'il peut faire ces miracles que tu s ne voyez des miracles et des |



Collocations

Word preferences: Words that occur together

| | English | French | German |
|---------------|--------------------------|----------------------------|-------------------------|
| You say | <i>Strong tea</i> | <i>Thé fort</i> | <i>Schmales Gesicht</i> |
| | <i>Powerful computer</i> | <i>Ordinateur puissant</i> | <i>Enge Kleidung</i> |
| You don't say | <i>Strong computer</i> | <i>Thé puissant</i> | <i>Schmale Kleidung</i> |
| | <i>Powerful tea</i> | <i>Ordinateur fort</i> | <i>Enges Gesicht</i> |



Word Preferences

| Strong w | | | Powerful w | | |
|-----------------|-------------------|----------|-----------------|-------------------|----------|
| <i>strong w</i> | <i>powerful w</i> | <i>w</i> | <i>strong w</i> | <i>powerful w</i> | <i>w</i> |
| 161 | 0 | showing | 1 | 32 | than |
| 175 | 2 | support | 1 | 32 | figure |
| 106 | 0 | defense | 3 | 31 | minority |
| ... | | | | | |



Corpora as Knowledge Sources

Short term:

- Describe usage more accurately
- Assess tools: part-of-speech taggers, parsers.
- Learn statistical/machine learning models for speech recognition, taggers, parsers
- Derive automatically symbolic rules from annotated corpora

Longer term:

- Semantic processing
- Texts are the main repository of human knowledge



Finite-State Automata

A flexible tool to search and process text

A FSA accepts and generates strings, here *ac*, *abc*, *abbc*, *abbbc*, *abbbbbbbbbbbbc*, etc.



FSA

Mathematically defined by

- Q a finite number of states;
- Σ a finite set of symbols or characters: the input alphabet;
- q_0 a start state,
- F a set of final states $F \subseteq Q$
- δ a transition function $Q \times \Sigma \rightarrow Q$ where $\delta(q, i)$ returns the state where the automaton moves when it is in state q and consumes the input symbol i .



FSA in Prolog

```
% The start state      % The final states
start(q0).             final(q2).
```

```
transition(q0, a, q1).
transition(q1, b, q1).
transition(q1, c, q2).
```

```
accept(Symbols) :-
    start(StartState),
    accept(Symbols, StartState).
```

```
accept([], State) :-
    final(State).
accept([Symbol | Symbols], State) :-
    transition(State, Symbol, NextState),
    accept(Symbols, NextState).
```



FSA with OpenFst

OpenFst (<http://openfst.org>) is a comprehensive library to build and process transducers.

OpenFst represents automata in a tabular format

The first transition is represented by the line:

```
0 1 a
```

and the whole automaton by (fsa1.fst):

```
0 1 a
```

```
1 1 b
```

```
1 2 c
```

```
2
```



FSA with OpenFst (II)

OpenFst only accepts numbers and we need to provide it with a conversion table, where we encode the symbols as integers (symbols.txt):

```
<epsilon> 0  
a 1  
b 2  
c 3
```

OpenFst compiles the text files into a binary format (fsa1.bin):

```
$ fstcompile --isymbols=symbols.txt --osymbols=symbols.txt \  
--acceptor fsa1.fst fsa1.bin
```



FSA with OpenFst (III)

Inputs, *abbc* or *abbc**b***, are entered as linear chain automata:

The sequence *abbc* in file
input1.fst

```
0 1 a
1 2 b
2 3 b
3 4 c
4
```

The sequence *abbc**b*** in
input2.fst

```
0 1 a
1 2 b
2 3 b
3 4 c
4 5 b
5
```

```
$ fstcompose input1.bin fsa1.bin | fstprint --acceptor \
--isymbols=symbols.txt
```

```
0 1 a
1 2 b
2 3 b
3 4 c
4
```



Regular Expressions

Regexes are equivalent to FSA and generally easier to use
Constant regular expressions:

| Pattern | String |
|---------|--|
| regular | <i>A section on <u>regular</u> expressions</i> |
| the | <i>The book of <u>the</u> life</i> |

The automaton above is described by the regex `ab*c`

```
grep 'ab*c' myFile1 myFile2
```

While `grep` was the first regex tool, most programming languages adopt the Perl syntax



regex101.com

regex101.com: A site to experiment and test regular expressions.

The screenshot displays the regex101.com web application. The interface is divided into several sections:

- REGULAR EXPRESSION:** The input field contains `/ac*e/g`. A status bar above it indicates "3 MATCHES - 21 STEPS".
- TEST STRING:** The input field contains the text "The aerial acceleration alerted the ace pilot". The words "aerial", "acceleration", and "ace" are highlighted in blue, indicating they match the pattern.
- EXPLANATION:** This section provides details about the matches:
 - `/ac*e/g`
 - `a` matches the character `a` literally (case sensitive)
 - `c*` matches the character `c` literally (case sensitive)
 - Quantifier: `*` Between `zero` and
- MATCH INFORMATION:** This section states: "No match groups were extracted. This means that your pattern matches but there were no `(capturing groups)` in it that matched anything in the subject string."
- QUICK REFERENCE:** This section includes links for "FULL REFERENCE", "MOST USED TOKENS", and "CATEGORIES".
- FLAVOR:** A sidebar on the left lists different regex flavors: PCRE (selected), JS, and PY.
- TOOLS:** A sidebar on the left contains icons for various tools, including a menu icon, a code icon, a search icon, and a checkmark icon.
- SUBSTITUTION:** A section at the bottom for defining replacement strings.

Metacharacters

| Chars | Descriptions | Examples |
|-------|--|---|
| * | Matches any number of occurrences of the previous character – zero or more | ac*e matches strings ae, ace, acce, accce, etc. as in “The <u>a</u> erial <u>a</u> cceleration alerted the <u>a</u> ce pilot” |
| ? | Matches at most one occurrence of the previous character – zero or one | ac?e matches ae and ace as in “The <u>a</u> erial acceleration alerted the <u>a</u> ce pilot” |
| + | Matches one or more occurrences of the previous character | ac+e matches ace, acce, accce, etc. as in as in “The aerial <u>a</u> cceleration alerted the <u>a</u> ce pilot” |



Metacharacters

| Chars | Descriptions | Examples |
|--------------------|---|---|
| <code>{n}</code> | Matches exactly n occurrences of the previous character | <code>ac{2}e</code> matches <code>acce</code> as in “The aerial <u>ac</u> celeration alerted the ace pilot” |
| <code>{n,}</code> | Matches n or more occurrences of the previous character | <code>ac{2,}e</code> matches <code>acce</code> , <code>accce</code> , etc. |
| <code>{n,m}</code> | Matches from n to m occurrences of the previous character | <code>ac{2,4}e</code> matches <code>acce</code> , <code>accce</code> , and <code>acccece</code> . |

Literal values of metacharacters must be quoted using `\`



The Dot Metacharacter

The dot `.` is a metacharacter that matches one occurrence of any character except a new line

`a.e` matches the strings *ale* and *ace* in:

The aerial acceleration alerted the ace pilot

as well as *age, ape, are, ate, awe, axe, or aae, aAe, abe, aBe, a1e*, etc.

`.*` matches any string of characters until we encounter a new line.



The Longest Match

The previous slide does not tell about the match strategy.

Consider the string *aabbc* and the regular expression *a+b**

By default the match engine is greedy: It matches as early and as many characters as possible and the result is *aabb*

Sometimes a problem. Consider the regular expression *.** and the phrase

They match as early and as many characters as they can.

It is possible to use a lazy strategy with the **?* metacharacter instead: *.*?* and have the result:

They match as early and as many characters as they can.



Character Classes

[...] matches any character contained in the list.

[^...] matches any character not contained in the list.

[abc] means one occurrence of either a, b, or c

[^abc] means one occurrence of any character that is not an a, b, or c,

[ABCDEFGHIJKLMNOPQRSTUVWXYZ] one upper-case unaccented letter

[0123456789] means one digit.

[0123456789]+\.[0123456789]+ matches decimal numbers.

[Cc]omputer [Ss]cience matches Computer Science,
computer Science, Computer science, computer science.



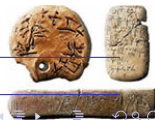
Predefined Character Classes

| Expr. | Description | Example |
|-----------------|---|---|
| <code>\d</code> | Any digit. Equivalent to <code>[0-9]</code> | <code>A\dC</code> matches <code>A0C</code> , <code>A1C</code> , <code>A2C</code> , <code>A3C</code> etc. |
| <code>\D</code> | Any nondigit. Equivalent to <code>[^0-9]</code> | |
| <code>\w</code> | Any word character: letter, digit, or underscore. Equivalent to <code>[a-zA-Z0-9_]</code> | <code>1\w2</code> matches <code>1a2</code> , <code>1A2</code> , <code>1b2</code> , <code>1B2</code> , etc |
| <code>\W</code> | Any nonword character. Equivalent to <code>[^\w]</code> | |
| <code>\s</code> | Any white space character: space, tabulation, new line, form feed, etc. | |
| <code>\S</code> | Any nonwhite space character. Equivalent to <code>[^\s]</code> | |



Nonprintable Symbols or Positions

| Char. | Description | Example |
|-----------------|-----------------------------|---|
| <code>^</code> | Matches the start of a line | <code>^ab*c</code> matches <code>ac</code> , <code>abc</code> , <code>abbc</code> , etc. when they are located at the beginning of a new line |
| <code>\$</code> | Matches the end of a line | <code>ab?c\$</code> matches <code>ac</code> and <code>abc</code> when they are located at the end of a line |
| <code>\b</code> | Matches word boundaries | <code>\babc</code> matches <code>abcd</code> but not <code>dabc</code> <code>bcd\b</code> matches <code>abcd</code> but not <code>abcde</code> |
| <code>\n</code> | Matches a new line | <code>a\nb</code> matches <code>a</code> <code>b</code> |
| <code>\t</code> | Matches a tabulation | |



Union and Boolean Operators

Union denoted $|$: $a|b$ means either a or b .

Expression $a|bc$ matches the strings a and bc and $(a|b)c$ matches ac and bc ,

Order of precedence:

- 1 Closure and other repetition operator (highest)
- 2 Concatenation, line and word boundaries
- 3 Union (lowest)

abc^* is the set ab , abc , $abcc$, $abccc$, etc.

$(abc)^*$ corresponds to abc , $abcabc$, $abcabcabc$, etc.



Python

Match: m/regex/

```
import regex as re
```

```
line = 'The aerial acceleration alerted the ace pilot'
```

```
match = re.search('ab*c', line)
```

```
match      # <regex.Match object; span=(11, 13), match='ac'>
```

```
match.group() # ac
```

The `re.search()` function stops at the first match.



Python

Use `findall()` or `finditer()` to return all the matches

Match: `m/regex/g`

```
match_list = re.findall('ab*c', line)    # ['ac', 'ac']
```

Match: `m/regex/g`

```
match_iter = re.finditer('ab*c', line)
list(match_iter)
# [<regex.Match object; span=(11, 13), match='ac'>,
#  <regex.Match object; span=(36, 38), match='ac'>]
```



Python

Match: m/regex/modifiers

```
text = sys.stdin.read()
match = re.search('^ab*c', text, re.I | re.M) # m/^ab*c/im
if match:
    print('-> ' + match.group())
```



Python

Substitute: s/regex/replacement/g

```
for line in sys.stdin:
    if re.search('ab+c', line):
        print("Old: " + line, end='')
        # Replaces all the occurrences
        line = re.sub('ab+c', 'ABC', line)    # s/ab+c/ABC/g
        print("New: " + line, end='')
```

Substitute: s/regex/replacement/

If we just want to replace the first occurrence, we use this statement instead:

```
# Replaces the first occurrence
line = re.sub('ab+c', 'ABC', line, 1) # s/ab+c/ABC/
```

Python

Back references

The instruction `m/(.)\1\1/` matches sequences of three identical characters:

```
line = 'abbbcddeef'
match = re.search(r'(\.)\1\1', line)
match.group(1)           # 'b'
```

We need to use a raw string and the `r` prefix to encode the regex in `search()`, otherwise `\1` would be interpreted as an octal number

Substitutions

```
s/(\.)\1\1/***/g

re.sub(r'(\.)\1\1', '***', 'abbbcddeef') # 'a***cd***f'
```

Python

Multiple back references

Python can create as many buffers as we need: \1, \2, \3, etc. Outside the regular expression, the \<digit> reference is returned by `group(<digit>)`: `match_object.group(1)`, `match_object.group(2)`, `match_object.group(3)`, etc.

Multiple back references

```
m/\$ *([0-9]+)\.?([0-9]*)/
```

```
price = "We'll buy it for $72.40"
match = re.search('\$ *([0-9]+)\.?([0-9]*)', price)
match.group()           # '$72.40' The entire match
match.group(1)          # '72' The first group
match.group(2)          # '40' The second group
```

Python

Substitutions

```
s/\$ *([0-9]+)\.?([0-9]*)/\1 dollars and \2 cents/g
```

```
price = "We'll buy it for $72.40"
```

```
re.sub('\$ *([0-9]+)\.?([0-9]*)',
```

```
      r'\1 dollars and \2 cents', price)
```

```
# We'll buy it for 72 dollars and 40 cents
```



Python

Match objects

- `match_object.group()` or `match_object.group(0)` return the entire match;
- `match_object.group(n)` returns the *n*th parenthesized subgroup.

In addition, the `match_object.groups()` returns a tuple with all the groups and the `match_object.string` instance variable contains the input string.

```
price = "We'll buy it for $72.40"
match = re.search('\$ *([0-9]+)\.?([0-9]*)', price)
match.string           # We'll buy it for $72.40
match.groups()         # ('72', '40')
```



Python

Match objects

We extract the indices of the matched substrings with the functions:

```
match_object.start([group])  
match_object.end([group])
```

```
line = """Tell me, O muse, of that ingenious hero  
        who travelled far and wide after he had sacked  
        the famous town of Troy."""
```

```
match = re.search(',.*,', line, re.S)  
line[0:match.start()]           # 'Tell me'  
line[match.start():match.end()] # ', O muse,'  
line[match.end():]              # 'of that ingenious hero  
                                #  who travelled far and wide after he had sacked  
                                #  the famous town of Troy.'
```

A Regex to Find Concordances

To print concordances, we need to write a regex that matches the pattern as well as a left and right context.

For instance *Nils Holgersson* with a context of 15 characters:

```
.{0,15}Nils Holgersson.{0,15}
```

Ideally, we would pass pattern and width as parameters:

```
pattern = 'Nils Holgersson'  
width = 15  
'.{0,width}pattern.{0,width}'
```



format()

`str.format()` provides variable substitutions as in:

```
begin = 'my'
'{} string {}'.format(begin, 'is empty')
# 'my string is empty'
```

`format()` has many options like reordering the arguments through indices:

```
begin = 'my'
'{1} string {0}'.format('is empty', begin)
# 'my string is empty'
```

If the input string contains braces, we escape them by doubling them: `{{` for a literal `{` and `}}` for `}`.

```
('.{0},{width}}{pattern}.{0},{width}}'
    .format(pattern=pattern, width=width))
```



Concordances in Python

```
[file_name, pattern, width] = sys.argv[1:]
try:
    text = open(file_name).read()
except:
    print('Could not open file', file_name)
    exit(0)

# spaces match tabs and newlines
pattern = re.sub(' ', '\\s+', pattern)
# Replaces newlines with spaces in the text
text = re.sub('\\s+', ' ', text)
concordance = ('({0,{width}}}{pattern}.{0,{width}})'.
               .format(pattern=pattern, width=width))
for match in re.finditer(concordance, text):
    print(match.group(1))
```



Approximate String Matching

A set of edit operations that transforms a source string into a target string: copy, substitution, insertion, deletion, reversal (or transposition).

Edits for *acress* from Kernighan et al. (1990).

| Typo | Correction | Source | Target | Position | Operation |
|--------|------------|--------|--------|----------|---------------|
| acress | actress | — | t | 2 | Deletion |
| acress | cress | a | — | 0 | Insertion |
| acress | caress | ac | ca | 0 | Transposition |
| acress | access | r | c | 2 | Substitution |
| acress | across | e | o | 3 | Substitution |
| acress | acres | s | — | 4 | Insertion |
| acress | acres | s | — | 5 | Insertion |



Building a Spell Checker

Spell checkers use a dictionary and a set of transformations to suggest corrections to misspelled words in a text.

Dictionaries are collected from well-written texts: novels, newspapers, etc.

- Given a word in a text not in the dictionary, the spell checker generates all the transformations of this word.
- If we allow only one edit operation on a source string of length n , and if we consider an alphabet of 26 unaccented letters,
 - the deletion will generate n new strings;
 - the insertion, $(n + 1) \times 26$ strings;
 - the substitution, $n \times 25$; and
 - the transposition, $n - 1$ new strings.
- The spell checker keeps the transformations that are in the dictionary and orders them by frequency to suggest the correct word.

For an implementation, see <http://norvig.com/spell-correct.html>



Building a Spell Checker

```
freq('acres') = 36.  
freq('caress') = 3.  
freq('cress') = false.  
freq('actress') = 7.  
freq('access') = 56.  
freq('across') = 222.
```



Distance between ab and cb



Edit distances measure the similarity between strings.

Let us align

| | | |
|---|---|-------------|
| a | b | Source |
| c | b | Destination |

| | | | |
|-------|-------|---|---|
| b | 2 | | |
| c | 1 | | |
| Start | 0 | 1 | 2 |
| | Start | a | b |



Minimum Edit Distance

We compute the minimum edit distance using a matrix where the value at position (i,j) is defined by the recursive formula:

$$\text{edit_distance}(i,j) = \min \begin{pmatrix} \text{edit_distance}(i-1,j) + \text{del_cost} \\ \text{edit_distance}(i-1,j-1) + \text{subst_cost} \\ \text{edit_distance}(i,j-1) + \text{ins_cost} \end{pmatrix}.$$

where $\text{edit_distance}(i,0) = i$ and $\text{edit_distance}(0,j) = j$.



Edit Operations



Usually, $del_cost = ins_cost = 1$
 $subst_cost = 2$ if $source(i) \neq target(j)$
 $subst_cost = 0$ if $source(i) = target(j)$.



Distance between ab and cb



Let us align

| | | |
|---|---|-------------|
| a | b | Source |
| c | b | Destination |

| | | | |
|-------|-------|---|---|
| b | 2 | | |
| c | 1 | | |
| Start | 0 | 1 | 2 |
| | Start | a | b |



Distance between ab and cb



Let us align

| | | |
|---|---|-------------|
| a | b | Source |
| c | b | Destination |

| | | | |
|-------|-------|---|---|
| b | 2 | | |
| c | 1 | 2 | |
| Start | 0 | 1 | 2 |
| | Start | a | b |



Distance between ab and cb



Let us align

| | | |
|---|---|-------------|
| a | b | Source |
| c | b | Destination |

| | | | |
|-------|-------|---|---|
| b | 2 | 3 | |
| c | 1 | 2 | 3 |
| Start | 0 | 1 | 2 |
| | Start | a | b |



Distance between ab and cb



Let us align

| | | |
|---|---|-------------|
| a | b | Source |
| c | b | Destination |

| | | | |
|-------|-------|---|----------|
| b | 2 | 3 | 2 |
| c | 1 | 2 | 3 |
| Start | 0 | 1 | 2 |
| | Start | a | b |



Distance between *language* and *lineage*

| | | | | | | | | | |
|-------|-------|---|---|---|---|---|---|---|---|
| e | 7 | | | | | | | | |
| g | 6 | | | | | | | | |
| a | 5 | | | | | | | | |
| e | 4 | | | | | | | | |
| n | 3 | | | | | | | | |
| i | 2 | | | | | | | | |
| l | 1 | | | | | | | | |
| Start | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| | Start | l | a | n | g | u | a | g | e |



Distance between *language* and *lineage*

| | | | | | | | | | |
|-------|-------|---|---|---|---|---|---|---|---|
| e | 7 | 6 | 5 | | | | | | |
| g | 6 | 5 | 4 | | | | | | |
| a | 5 | 4 | 3 | | | | | | |
| e | 4 | 3 | 4 | | | | | | |
| n | 3 | 2 | 3 | | | | | | |
| i | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| l | 1 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Start | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| | Start | l | a | n | g | u | a | g | e |



Distance between *language* and *lineage*

| | | | | | | | | | |
|-------|-------|---|---|---|---|---|---|---|---|
| e | 7 | 6 | 5 | 6 | 5 | 6 | 7 | 6 | 5 |
| g | 6 | 5 | 4 | 5 | 4 | 5 | 6 | 5 | 6 |
| a | 5 | 4 | 3 | 4 | 5 | 6 | 5 | 6 | 7 |
| e | 4 | 3 | 4 | 3 | 4 | 5 | 6 | 7 | 6 |
| n | 3 | 2 | 3 | 2 | 3 | 4 | 5 | 6 | 7 |
| i | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| l | 1 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Start | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| | Start | l | a | n | g | u | a | g | e |



Python Code

```
[source, target] = sys.argv[1:]

length_s = len(source)
length_t = len(target)

# Initialize first row and column
table = [None] * (length_s + 1)

for i in range(length_s):
    table[i] = [None] * (length_t + 1)
    table[i][0] = i
for j in range(length_t):
    table[0][j] = j
```



Python Code

```
# Fills the table. Start index of rows and columns is 1
for i in range(1, length_s):
    for j in range(1, length_t):
        # Is it a copy or a substitution?
        cost = 0 if source[i - 1] == target[j - 1] else 2
        # Computes the minimum
        minimum = table[i - 1][j - 1] + cost
        if minimum > table[i][j - 1] + 1:
            minimum = table[i][j - 1] + 1
        if minimum > table[i - 1][j] + 1:
            minimum = table[i - 1][j] + 1
        table[i][j] = minimum

print('Minimum distance: ', table[length_s - 1][length_t - 1])
```



Prolog Code

```
% edit_operation carries out one edit operation
% between a source string and a target string.
edit_operation([Char | Source], [Char | Target], Source,
    Target, ident, 0).
edit_operation([SChar | Source], [TChar | Target], Source,
    Target, sub(SChar,TChar), 2) :-
    SChar \= TChar.
edit_operation([SChar | Source], Target, Source, Target,
    del(SChar), 1).
edit_operation(Source, [TChar | Target], Source, Target,
    ins(TChar), 1).
```



Prolog Code

```
% edit_distance(+Source, +Target, -Edits, ?Cost).
edit_distance(Source, Target, Edits, Cost) :-
    edit_distance(Source, Target, Edits, 0, Cost).

edit_distance([], [], [], Cost, Cost).
edit_distance(Source, Target, [EditOp | Edits], Cost,
    FinalCost) :-
    edit_operation(Source, Target, NewSource, NewTarget,
        EditOp, CostOp),
    Cost1 is Cost + CostOp,
    edit_distance(NewSource, NewTarget, Edits, Cost1,
        FinalCost).
```



Distance between *language* and *lineage*

| | First alignment | Third alignment |
|-------------------------|-----------------|-------------------|
| Without epsilon symbols | l a n g u a g e | l a n g u a g e |
| | / / / | / / / |
| | l i n e a g e | l i n e a g e |
| With epsilon symbols | l a n g u a g e | l a n g u ε a g e |
| | | |
| | l i n e ε a g e | l i n ε ε e a g e |

