Introduction to Natural Language Processing

Out of Vocabulary Forms

Spelling Error correction

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Contents

Out of Vocabulary forms

- Out of Vocabulary (OoV) forms matter: they occur quite frequently (e.g. $\simeq 10\%$ in newspapers)

  What do they consist of?

  – spelling errors: *foget*, *summmary*, *usqge*, ...

  – neologisms: *Internetization*, *Tacherism*, ...

  – borrowings: *gestalt*, *rendez-vous*, ...

  – forms difficult to exhaustively lexicalize: (numbers,) proper names, abbreviations, ...

- identification based on patterns is not well-adapted for all OoV forms

  ☞ We will focus here on spelling errors, neologisms and borrowings

Spelling errors and neologisms

- for **spelling errors** (resp. **neologisms**), distortions (resp. derivations) are modelled by *transformations*, i.e. rewriting rules (sometimes weighted)

  Example:

  – Transposition (distortion): `XY` $\rightarrow$ `YX [1.0]`

    where `X` and `Y` stands for variables

  – tripling (distortion): `XX` $\rightarrow$ `XXX [1.0]`

  – name derivation: `ize:INF` $\rightarrow$ `ization:N [1.0]`

- a given lexicon (regular language) and a set of transformations define the edit space to be explored

  ☞ The aim is to find the position of the OoV forms in the edit space with respect to known (lexicalized) forms (*neighbourhoods*, *similarity*, *distance*)

Spelling errors and neologisms (2)

- if the transformation set is simple enough: automatic (or semi-automatic) learning of the transformation set is possible

  Examples:

  - morphological rules for Spanish
  - transformations for spelling error correction after OCR

Borrowings

For **borrowings** ☞ **identification of the source language**

[when no large coverage lexica are avalaible for the other languages, but only representative texts]

Decomposition into n-grams of characters: *Example*: for trigrams

dribble $\longrightarrow$ (dri,rib,ibb,bbl,ble)

In practice: n varies from 2 to 4

From reference corpora, computation of a frequency matrix (n-gram $\times$ language)

☞ approximation of likelihood of a word to belong to a given language

Example for trigrams:

$$V(\text{dribble}, L) = P(\text{dribble}|L) = P(\text{dri}|L) \cdot \frac{P(\text{rib}|L)}{P(\text{ri}|L)} \cdot \ldots \cdot \frac{P(\text{ble}|L)}{P(\text{bl}|L)}$$

Trigrams for French, English, German and Spanish: 87% discrimination accuracy

n-gram approach

A sequence of xs (letters, words, ...; was letters in the former case)

$(n-1)$-order Markov assumption:

$$P(x_1 \cdots x_N) = P(x_1 \cdots x_{n-1}) \cdot \prod_{i=n}^{N} P(x_i | x_{i-n+1} \cdots x_{i-1})$$

i.e. use this as a score to compare sequences ($n \geq 2$):

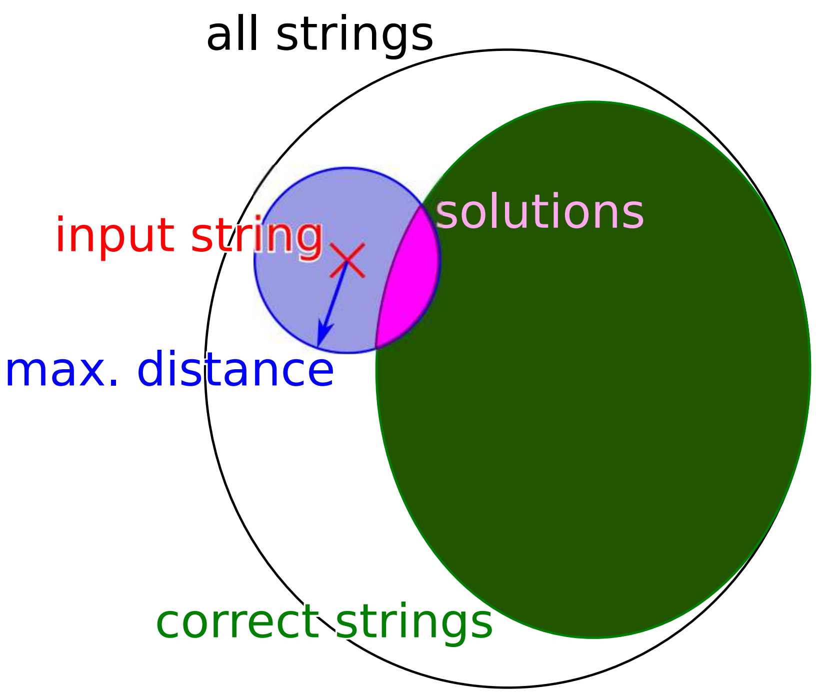
$$\frac{\displaystyle\prod_{i=1}^{N-n+1} P(x_i \cdots x_{i+n-1})}{\displaystyle\prod_{i=2}^{N-n+1} P(x_i \cdots x_{i+n-2})}$$

$P(x_i \cdots x_{i+n-1})$ being estimated on some corpus

Reminder: $P(x_i \cdots x_{i+n-2}) = \sum_{x} P(x_i \cdots x_{i+n-2}\, x)$

Contents

Spelling error correction



Two approaches:

	Exact lexicon-based	Statistical
correct forms:	lexicon	any string
metric:	edit distance	probability

In this lecture: exact, lexicon-based

For statistical: see http://norvig.com/spell-correct.html

Edit distance

also called Levenshtein distance

☞ distance between 2 forms

= minimal number of transformations to change one into the other

Example of transformations:

- insertion: *exmple* $\longrightarrow$ *example*
- deletion: *example* $\longrightarrow$ *exmple*
- substitution: *exemple* $\longrightarrow$ *example*
- transposition: *exmaple* $\longrightarrow$ *example*

Computation of edit distance (1)

Notations:

X_i: ith char of string X

X_i^j: if $i \leq j$: substring X_i,...,X_j; empty string otherwise

Example: X = castle

X_3 = s $\quad$ X_4^6 = tle $\quad$ X_1^4 = cast $\quad$ X_1^0 = ε

Computation of the distance $D(X, Y)$ by dynamic programming:

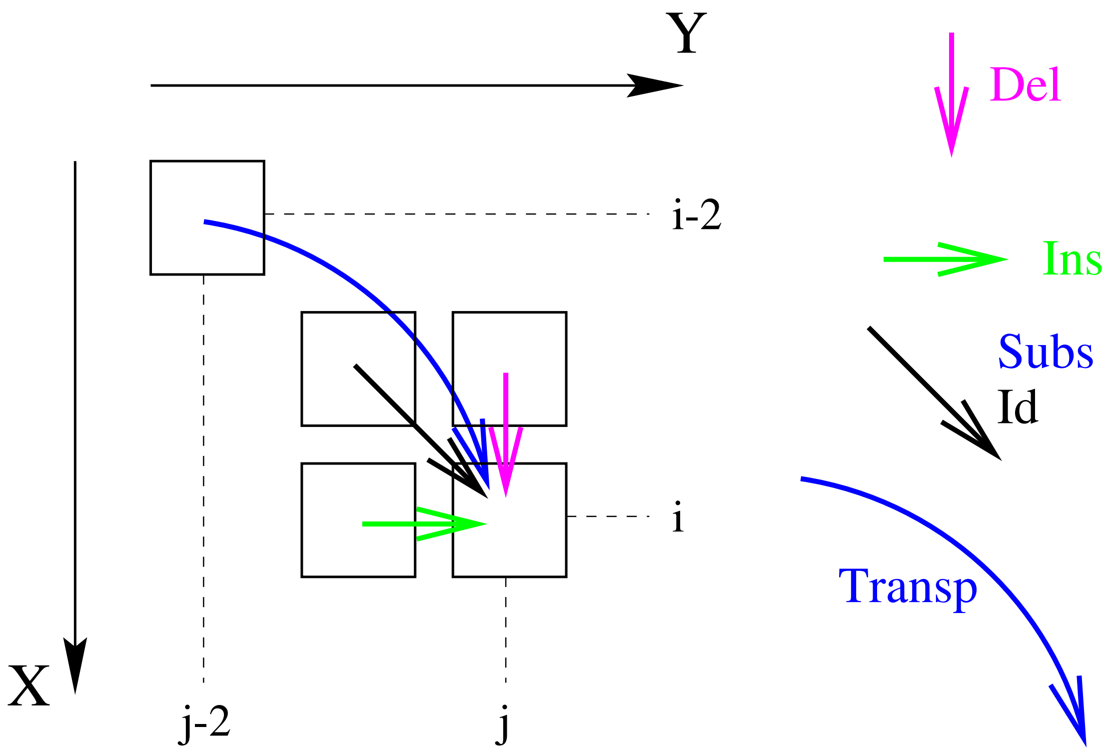
☞ step by step in a chart m where each cell m_{ij} contains the distance between the two substrings X_1^i and Y_1^j :

$$m_{ij} = D(X_1^i, Y_1^j)$$

Computation of edit distance (2)

$D(X_1^0;Y_1^j)$	= j	initialization
$D(X_1^i;Y_1^0)$	= i	
$D(X_1^i;Y_1^j)$	= $D(X_1^{i-1};Y_1^{j-1})$	**if** $X_i = Y_j$ (equality)
	= $1 + \min\left\{D(X_1^{i-2};Y_1^{j-2}), D(X_1^{i-1};Y_1^{j}), D(X_1^{i};Y_1^{j-1})\right\}$	**else if** $i \geq 2$ and $j \geq 2$ and $X_{i-1} = Y_j$ and $X_i = Y_{j-1}$ (transposition, deletion, insertion)
	= $1 + \min\left\{D(X_1^{i-1};Y_1^{j-1}), D(X_1^{i-1};Y_1^{j}), D(X_1^{i};Y_1^{j-1})\right\}$	**else** (substitution, deletion, insertion)

Computation order



☞ several possible ways of computing: rowwise, columnwise or diagonal

Computation of edit distance (3)

Example, columnwise:

for all i from 0 to $|X|$ (size of X) **do**

$m_{i0} = i$

for all j from 1 to $|Y|$ **do**

$m_{0j} = j$

for all i from 1 to $|X|$ **do**

if $X_i = Y_j$ **then**

$m_{ij} = m_{i-1,j-1}$

else if $i \geq 2$ and $j \geq 2$ and $X_{i-1} = Y_j$ and $X_i = Y_{j-1}$ **then**

$m_{ij} = 1 + \min\left\{m_{i-2,j-2};\ m_{i,j-1};\ m_{i-1,j}\right\}$

else

$m_{ij} = 1 + \min\left\{m_{i-1,j-1};\ m_{i,j-1};\ m_{i-1,j}\right\}$

Return $m_{|X|,|Y|}$

Edit Distance (example)

D(exmple;exemple)

		e	x	e	m	p	l	e
	0	1	2	3	4	5	6	7
e	1	0	1	2	3	4	5	6
x	2	1	0	1	2	3	4	5
m	3	2	1	1	1	2	3	4
p	4	3	2	2	2	1	2	3
l	5	4	3	3	3	2	1	2
e	6	5	4	3	4	3	2	1

D(exmaple;example)

		e	x	a	m	p	l	e
	0	1	2	3	4	5	6	7
e	1	0	1	2	3	4	5	6
x	2	1	0	1	2	3	4	5
m	3	2	1	1	1	2	3	4
a	4	3	2	1	1	2	3	4
p	5	4	3	2	2	1	2	3
l	6	5	4	3	3	2	1	2
e	7	6	5	4	4	3	2	1

Spelling error correction using a FSA

Problem: approximative search of lexicalized (surface) forms

= within a max. distance range

i.e. Fault-tolerant recognition (within a regular language):

Find **all** ending paths such that the corresponding string is within a distance range less than $\underline{\theta}$ of the given input string.

Remark: a trie is a special case of FSA

Pruning criteria: cut-off edit distance

To make it useful in practice $\Rightarrow$ Fast $\Rightarrow$ good pruning

☞ cut-off edit distance [Oflazer 1996]

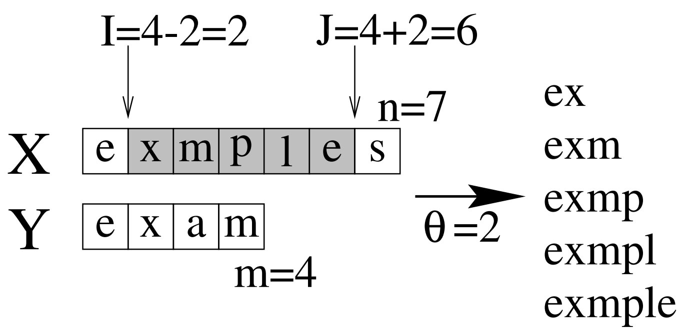
$$D_c(X_1^n, Y_1^m) = \min_{I(m) \leq i \leq J(m)} D(X_1^i; Y_1^m)$$

$$I(m) = \min(n, \max(1, m - \theta)) \qquad J(m) = \min(n, \max(1, m + \theta))$$

Important property:

$$D_c(X, Y) > \theta \implies \forall Z \; D(X, Y + Z) > \theta$$

Cut-off Edit Distance: example



Y

		e	x	a	m
	0	1	2	3	4
e	1	0	1	2	3
x	2	1	0	1	2
m	3	2	1	1	1
p	4	3	2	2	2
l	5	4	3	3	3
e	6	5	4	4	4
s	7	6	5	5	5

X

$$D_c(X,Y) = \min\{2,1,2,3,4\} = 1$$

Walk through a FSA within a θ distance range

Original algorithm

Input: a string to be corrected (X), a lexicon in the form of a FSA and a maximal error threshold (θ)

Push(ε, q_0) — ε: empty string, q_0: inital state

while Stack is not empty **do**

  Pop(Z, p)

  for all $a \in \Sigma$ **do**

    for all q such that $\delta(p, a) = q$ **do**

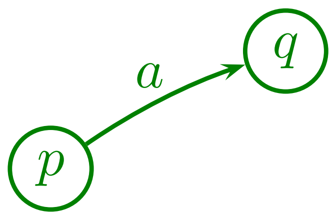
      $Y \leftarrow Z + a$

      if $D_c(X, Y) \leq \theta$ **then**

        Push(Y, q)

        if $q \in F$ **and** $D(X, Y) \leq \theta$ — F: set of final states **then**

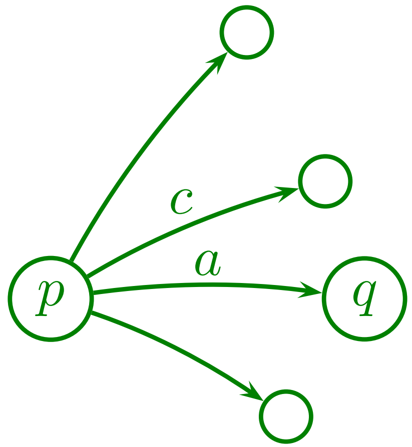
          Add Y to solutions



Walk through a FSA within a θ distance range

Prefix-compatible Depth-first version

Push($\varepsilon, \varepsilon, q_0$)
while Stack is not empty **do**
  Pop(Z, c, p)
  $(q, a) =$ nextAfter(p, c)
  if $(q, a) \neq \emptyset$ **then**
    Push(Z, a, p)
    $Y \leftarrow Z + a$
    if $D_c(X, Y) \leq \theta$ **then**
      Push(Y, ε, q)
      if $q \in F$ **and** $D(X, Y) \leq \theta$ **then**
        Add Y to solutions



where:

nextAfter$(p, c) = \mathrm{Argmin}_\alpha \{(q, \alpha) \in Q \times \Sigma$ such that $\alpha > c$ and $\delta(p, \alpha) = q\}$

Implementation issues

① original version (simpler) .vs. Prefix-compatible Depth first (faster)

② Efficient computation of D_c with the previously described chart :

☞ recomputation of the last column (m) **only**

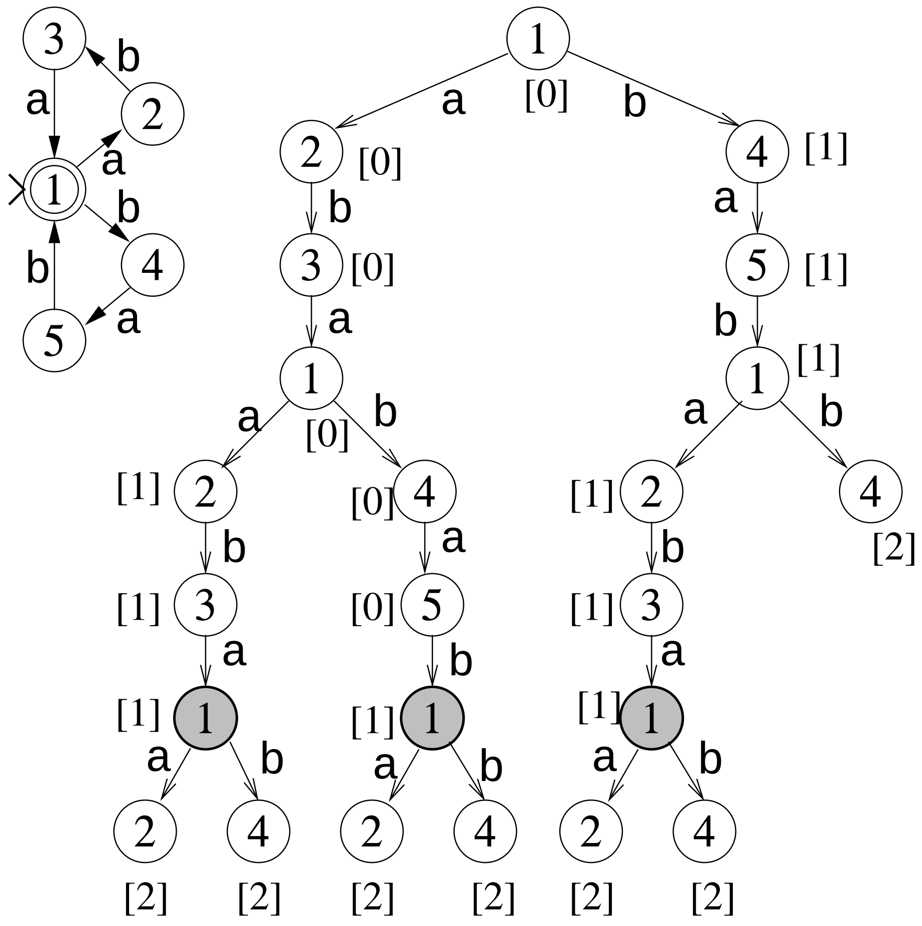
(pay attention to the backtrack case! Original version $\longrightarrow$ the last *two* columns)

☞ Computation of D and D_c in the **same** loop

③ $Y \leftarrow Z + a$: beware (local copies, pointers etc...).

Similarly, do not naively implement "Push(Y, q)".

④ In some languages (especially POO): it could be worth transposing the algorithm: Y (which is changing) for rows and X for columns



X=ababa .vs. (aba|bab)* for $\theta=1$

		a	b	a	a	b	a
	0	1	2	3	4	5	6
a	1	0	1	2	3	4	5
b	2	1	0	1	2	3	4
a	3	2	1	0	1	2	3
b	4	3	2	1	1	1	2
a	5	4	3	2	1	1	1

Solutions ☞ abaaba, ababab, bababa

Contents

- Out of Vocabulary Forms
- Spelling Error Correction
  - ✈ Edit distance
  - ✈ Spelling error correction with FSA
  - ➤ Weighted edit distance

Limitations?

➥ weighting

Example: diacritics, uppercase

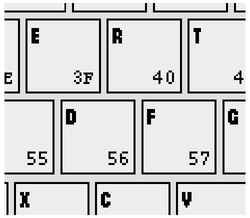
eleves $\longrightarrow$ *élèves* *aloves* $\longrightarrow$ *élèves*

➥ specific transformations

Example: typing errors

tupe $\longrightarrow$ *type* more generally: ***de**uit* $\longrightarrow$ *fruit*

*us**q**ge* $\longrightarrow$ *usage*



➥ whitespaces

theothers $\longrightarrow$ *the others* *othe rs* $\longrightarrow$ *others*

☞ 3 aspects of the **same** problem

Solution: generalization of the edit distance: weighted edit distance

Weighted Edit Distance

weighted transformations such that :

- $C(\mathrm{Id}) = 0$
- $C(\mathrm{f}) > 0 \qquad \mathrm{f} \neq \mathrm{Id}$
- $C(\mathrm{f}^{-1}) = C(\mathrm{f})$
- $C(\mathrm{f} \circ \mathrm{g}) = C(\mathrm{f}) + C(\mathrm{g})$

$$D(X;Y) = \min_{\mathrm{f}:Y=\mathrm{f}(X)} C(f)$$

☞ It is actually a distance on Σ^*

Difference with the preceding distance: $C(\mathrm{f})$ is not necessarily the same (= 1).

Remarks

❶ Distance on $\Sigma^* \Rightarrow \forall X\ Y, \quad \exists f : Y = f(X)$

True if Ins and Del are in the transformation set

❷ non overlapping transformations

i.e. cannot apply a transformation to the result of the previous transformation

Counter-Example: $\mathtt{ba} \stackrel{\mathrm{Transp}}{\longrightarrow} \mathtt{ab} \stackrel{\mathrm{Sub}}{\longrightarrow} \mathtt{ac}$

Coherence Constraints

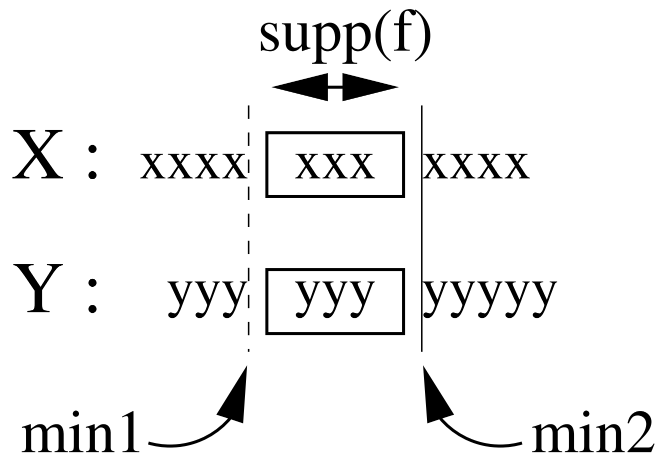
"Semantic Integrity":

- ❒ $C(\mathrm{Del}) + C(\mathrm{Ins}(x)) > C(\mathrm{Sub}(x))$
- ❒ $C(Split) < C(\mathrm{Ins}(x))$ ($\Rightarrow C(Merge) < C(\mathrm{Del})$)
- ❒ $C(\mathrm{Transp}) < C(\mathrm{Ins}(x)) + C(\mathrm{Del})$

☞ Introduction a new f such that $f = \circ_i f_i$, is useful if and only if

$$C(f) < \sum_i C(f_i)$$

Weighted Edit Distance: computation



$$\text{min2} = \min_{f} \left[\, \text{min1}(f) + C(f) \,\right]$$

(min1 and min2 are the values stored in the chart)

Weighted Edit Distance: computation (2)

$D(X_1^0; Y_1^j)$	=	j	initialization
$D(X_1^i; Y_1^0)$	=	i	
$D(X_1^i; Y_1^j)$	=	$D(X_1^{i-1}; Y_1^{j-1})$	if $X_i = Y_j$ (equality)
	=	$C(f) + \min\{\min_1(f)\}$	for all applicable transformations f of the same weight
	=	...	for all possible weights.

increasing $C(f)$

☞ The optimization lies in the grouping of similar cases: same weight and compatible transformations (Example: previously Transp and Sub were incompatible because $C(\mathrm{Transp}) < 2\,C(\mathrm{Sub})$. But each of them is compatible with Del and Ins.)

Note: $\{\min_1(f)\}$ is the set of all the minimal values for all possible f at this point; they shall, of course, already be computed at this point (loop condition)

Example

D(example;exemple)

		e	x	e	m	p	l	e
	0	1	2	3	4	5	6	7
e	1	0	1	2	3	4	5	6
x	2	1	0	1	2	3	4	5
a	3	2	1	1	2	3	4	5
m	4	3	2	2	1	2	3	4
p	5	4	3	3	2	1	2	3
l	6	5	4	4	3	2	1	2
e	7	6	5	4	4	3	2	1

D(exémple;exemple)

		e	x	e	m	p	l	e
	0	1	2	3	4	5	6	7
e	1	0	1	2	3	4	5	6
x	2	1	0	1	2	3	4	5
é	3	2	1	0.1	1.1	2.1	3.1	4.1
m	4	3	2	1.1	0.1	1.1	2.1	3.1
p	5	4	3	2.1	1.1	0.1	1.1	2.1
l	6	5	4	3.1	2.1	1.1	0.1	1.1
e	7	6	5	4	3.1	2.1	1.1	0.1

C(é↔e)=0.1

Keypoints

- One has to handle out of vocabulary forms
- Edit (Levenshtein) distance, weighted edit distance
- Spelling error correction with FSA

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