Analiticcl

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2022-01-20

Introduction

What is analiticcl?

- Analiticcl is a string-matching / fuzzy-matching system
- Intended for text normalisation like:
  - diachronic spelling variation
  - post-OCR/HTR variation
  - spelling correction (especially non-word errors)
- Lexicon-based; fuzzy lookups against a lexicon, using a smart *heuristic*

Introduction: Context

- Developed in the Golden Agents project
- Builds upon prior research (Reynaert 2010; Reynaert 2004)

Introduction: Implementation

- Built with performance and scalability in mind
  - Multi-threaded (parallellisation)
  - Written in Rust, compiles to native code
  - Low-level command-line tool and programming library
    - for Rust and for Python, via a binding
  - Unit/integration tests, CI, benchmarks
- Feature-rich
  - Highly parametrised
  - Flexible usage
- Source: https://github.com/proycon/analiticcl
- License: GNU GPLv3

Installation

Download, compile and install:

```
$ cargo install analiticcl
```

and/or for the Python binding:

```
$ pip install analiticcl
```

Fuzzy string matching

Core function: Fuzzy string matching

- Given a string, find the forms in the lexicon that are closest (**query** mode)
  - *error correction*
- Given a text, find corrections for arbitrary substrings in the text (**search** mode)
  - *error detection and correction*
- Given a lexicon entry, find close variants in the text (**learn** mode)

Example: Query mode

```
$ analiticcl query --interactive --lexicon examples/eng.aspell.lexicon \
                   --alphabet examples/simple.alphabet.tsv
Initializing model...
Loading lexicons...
Building model...
Computing anagram values for all items in the lexicon...
 - Found 119773 instances
Adding all instances to the index...
 - Found 108802 anagrams
Creating sorted secondary index...
Sorting secondary index...
 ...
Querying the model...
(accepting standard input; enter input to match, one per line)
seperate
seperate        separate        0.734375  \
                operate 0.6875 \
                desperate       0.6875   \
                temperate       0.6875          serrate 0.65625         separates       0.6
```

Recap: Edit Distance (Levenshtein)

- Measures distance/similarity between two strings
- Operations to go from string A to B (at a cost)
  - Insertions
  - Deletions
  - Substitutions
- Distance $=$ sum of costs

Variant matching: Naive approach

A naive approach to variant matching:

- Given m input words
- Compute edit distance (levenshtein) between each input word to all words in the lexicon (n)
- High computational cost! $O(mn)$, and the levenshtein algorithm itself has already a $O(l)$ (l=length) time complexity.
  - Does not scale

Variant matching: anagram hashing (1)

Anagram hashing (Reynaert 2010; Reynaert 2004) aims to drastically reduce the variant search space.

- Provides a fast *heuristic* for edit distance
- Analiticcl reimplements and improves upon the idea implemented in earlier tool TICCL

Variant matching: anagram hashing (2)

An Anagram Value (AV)..

- is computed for each 'word' in the input and in the lexicon
- uniquely represents the combination of characters in the word (unordered)
  - $AV(east) = AV(seat) = AV(eats)$
- has compositional properties:
  - $AV(eat) \cdot AV(s) = AV(eats)$
  - $\frac{AV(eats)}{AV(s)} = AV(eat)$
- each anagram value can be unambiguously decomposed to all its constituents
- no collisions between anagrams guaranteed (in this reimplementation)
- anagrams themselves deliberately collide
- serves as the key in a hash map (stores the lexicon)

Variant matching: hash function

Computation of the Anagram Value is simple composition of **prime** factors:

- **Input:** alphabet
- Each 'letter' in the alphabet is assigned a successive **prime number**, this is the Anagram Value of the 'letter'.
  - Example: $AV(a) = 2, AV(b) = 3, AV(c) = 7, AV(d) = 11, AV(e) = 17$
  - The use of prime number guarantees no collisions between anagrams
  - Novel with respect to Reynaert's approach.
- Simple hashing function (l=length, c_i=character at index i):

$$\prod_{i=0}^{l} AV(c_i)$$

- **Caveat:** May result in very large integers!
  - Exceeds 64-bit register
  - Requires an efficient big integer implementation

Variant matching: Search (1)

Loading stage: Compute Anagram Index and secondary index

- Compute Anagram Value for each entry in the lexicon and store in a hash map (the anagram index)
- Mapping the anagram value to all instances of the anagram:

$$AV(a, e, s, t) \mapsto [east, seat, eats]$$

- Compute a secondary index mapping to *sorted anagram values*:

$$(n, |s|) \mapsto L$$

  - where s is a string, $|s|$ its length in characters, and n it's length in words/tokens
  - where L is a *sorted* list of anagram values
  - example: $(1, 4) \mapsto [AV(a, e, s, t), ...]$

Variant matching: Search (2)

Search stage: Given a 'word' to correct:

- we compute the anagram value for the input
- we look up this anagram value in the anagram index (if it exists) and gather the variant candidates associated with the anagram value
- we compute all deletions within a certain distance (e.g. by removing any 2 characters).
    - Example with 1 character:

$$del(AV(a,e,s,t)) = [AV(a,e,s), AV(e,s,t), AV(a,s,t), AV(a,e,t)]$$

    - This is an arithmetic operation on the anagram values (division)

Variant matching: Search (3)

- For all of the anagram values resulting from these deletions we look which anagram values in our index *match or contain* the value under consideration. We again gather the candidates that result from all matches.
  - Match or contain: AV_a contains AV_b when

    $$AV_a \mod AV_b = 0$$

    .
  - To facilitate this lookup, we make use of the *secondary index*
  - Uses a binary search to find the anagrams that we should check our anagram value against (i.e. to check whether it is a subset of the anagram)
  - Prevents needing to exhaustively try all anagram values in our index.

Variant matching: Search, scoring and ranking (4)

After collecting applying the heuristic and collecting variants, reduce using more conventional means:

- We compute several similarity metrics between the input and the possible variants:
  - Damerau-Levenshtein
  - Longest common substring
  - Longest common prefix/suffix
  - Casing difference
- A score is computed that is a weighted linear combination of the above components
  - the actual weights are configurable.
  - an exact match always has score 1.0.
  - most score components are expressed as a fraction of the input length
- Frequency as an extra component
- Optionally, if a confusable list was provided, we adjust the score for known confusables

Parameters and weights

- Various parameters can be absolute and or relative to the pattern length:
  - Anagram distance
  - Edit distance (Damerau-Levenshtein)
  - Substring length
- Score threshold
- Cut-off threshold
- Max number of matches
- Weights: determines the importance of a component in the score function
  - Frequency ranking

Feature: Confusable lists

- A list of *confusable patterns* with a weight
- Allows favouring or penalizing certain edits
- Example: OCR pattern: `-[f]+[s]`
- Example: historical dutch pattern: `-[uy]+[ui]` (huys -> huis)
- Allows context matching
- Taken into account as part of the similarity score function

Input and output

Analiticcl takes simple TSV files (tab separated values) as input:

- **Lexicon**
  - List of preferably validated words/multi-word expressions
  - May contain frequency information
- **Variant list:** explicitly relates variants to preferred forms.
  - Each variant carries a score expression how likely the variant maps to the preferred word
  - May also contain frequency information
  - **Error list**; a form of a variant lists where the variants are considered errors
  - Example: `separate  seperate  1.0  seperete  1.0`
  - This is also the output form in *learn* mode
- **Language model**: for context-sensitive error detection/correction
- *Multiple* lexicons/variants lists supported
- Output is TSV or JSON

Background lexicon

- Analiticcl depends greatly on the quality of your input (lexicons)
- A good background lexicon is required (*out of vocabulary problem*)
  - including morphological variants
- ..otherwise analiticcl will eagerly mismatch to words it does know!
- Lexicon may also consist of phrases: less sensitive to false positives
  - cf. Fuzzy-Search (Marijn Koolen)

Learn Mode (1)

- Allows extending an existing lexicon with variants
  - Multiple iterations, covering larger edit distances
- Outputs a variant list
  - Can subsequently be used as input again
  - Possibly after manual curation

Learn Mode (2): Output example


```
{ "Amsterdam": [
    { "text": "Amsteldam", "score": 0.7499999999999999, "freq": 1 },
    { "text": "amsterdam", "score": 0.875, "freq": 1 },
    { "text": "Amster", "score": 0.625, "freq": 1 },
    { "text": "Amstelredam", "score": 0.6818181818181818, "freq": 1 },
    { "text": "Amsterd", "score": 0.7321428571428572, "freq": 1 },
    { "text": "Amstedam", "score": 0.765625, "freq": 1 },
    { "text": "sterdam", "score": 0.6071428571428572, "freq": 1 },
    { "text": "Amsterdm", "score": 0.796875, "freq": 1 },
    { "text": "Tamsterdam", "score": 0.8, "freq": 1 },
    { "text": "tamsterdam", "score": 0.675, "freq": 1 },
    { "text": "Amstelredame", "score": 0.6041666666666666, "freq": 1 },
    { "text": "t'Amsterdam", "score": 0.6136363636363636, "freq": 1 },
    { "text": "Asterdam", "score": 0.796875, "freq": 1 },
    { "text": "terdam", "score": 0.5, "freq": 1 },
    { "text": "Amstelredamm", "score": 0.6145833333333333, "freq": 1 },
    { "text": "t'amsterdam", "score": 0.6136363636363636, "freq": 1 },
    { "text": "Amterdam", "score": 0.78125, "freq": 1 },
    { "text": "msterdam", "score": 0.6875, "freq": 1 },
    { "text": "amsterd", "score": 0.6071428571428572, "freq": 1 },
    { "text": "tAmsterdam", "score": 0.675, "freq": 1 },
```

Error Detection (1)

- In **Query** mode, input is a word/phrase you want to correct as a whole
- In **Search** mode, input is running text: analiticcl detects which parts of the input (words or higher order n-grams) need to be corrected.
- An additional and complex challenge!
- **N-grams**: consider splits and merges:
  - *thehouse* → *the house* , *teahouse* ?
  - *tea house* → *the house* , *teahouse* ?
- **Context** is often a determining factor

Error Detection (2)

Given an input sentence:

1. Extract all segments of the input, i.e. all n-grams up until a certain order
2. Do variant lookup for each (like query mode)
3. Express all segments, their variants, their scores as transitions in a Finite State Transducer (FST)
   - Scores are expressed as costs
4. Extract the best path (lowest cost) with a beam search

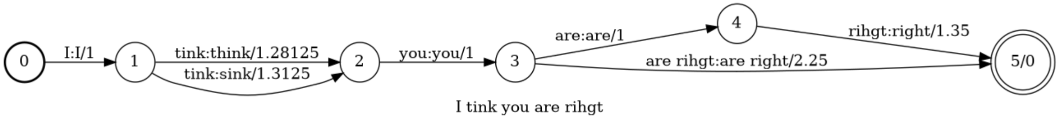

Figure 1: FST

Error Detection (3)

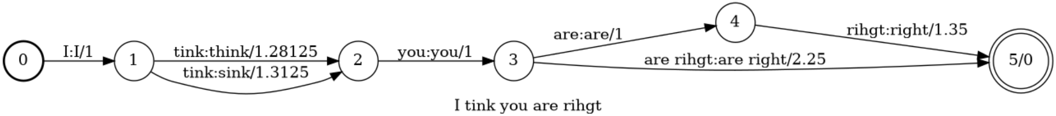

Figure 2: FST

- Scores are re-expressed as a cost (to be minimised)
- Base cost (integer) covers the number of input tokens spanned
  - establish a common ground for comparison between n-grams
  - n-grams compete
- Variant cost (fraction): inverse of the variant score: (0.0 best, approaching 1.0 as scores get worse)

$$cost = 1 - score$$

- **Joint variant score**: Sum of all costs on a complete path.
- Extract the 'cheapest' path(s)

Error Detection (4): Context

1. Extract the best n solutions from the FST (e.g. $n = 250$)
2. Compute the perplexity for each; using **Language Model**
3. Compute a weighted combined score of the perplexity and the joint variant score
   - Not trivial, strikes a balance between LM and variant model
   - Compute normalised joint variant score:

$$variantscore_i = \ln\left(\frac{cost_{best}}{cost_i}\right)$$

   - Compute normalised LM score:

$$lmscore_i = \ln\left(\frac{PP_{best}}{PP_i}\right)$$

   - Weighted geometric mean:

$$score_i = \frac{\lambda_1 variantscore_i + \lambda_2 lmscore_i}{\lambda_1 \lambda_2}$$

4. Select the best scoring solution (minimize score)

Error Detection (5): Output example

```
het     0:3     het     1
is      4:6     is      0.9879325407796102
een     7:10    een     0.953746422299111  \
                en      0.7713267631867726
huys    11:15   huis    0.8893535359305973  \
                huls    0.7993278799180914
```

Future Work

- Evaluation
  - Golden Agents
  - Spelling correction task?
- Comparative study
  - Analiticcl
  - TICCL
  - Fuzzy-Search
- **Questions?**

References

Software:

- Analiticcl: https://github.com/proycon/analiticcl
- TICCLtools: https://github.com/LanguageMachines/ticcltools
- Fuzzy-Search: https://github.com/marijnkoolen/fuzzy-search
- Golden Agents NER pipeline: https://github.com/knaw-huc/golden-agents-htr/tree/master/package

Publications:

- Reynaert, Martin. (2004) Text induced spelling correction. In: Proceedings COLING 2004, Geneva (2004). https://doi.org/10.3115/1220355.1220475
- Reynaert, Martin. (2011) Character confusion versus focus word-based correction of spelling and OCR variants in corpora. IJDAR 14, 173–187 (2011). https://doi.org/10.1007/s10032-010-0133-5